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PLANNING OF BUILDING FOR FAR NORTHERN REGIONS

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by

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PLANNING

~~DESIGN~~ OF BUILDINGS FOR ~~AREAS~~ far northern O~~F THE EXTREME NORTH~~ regions.

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DESIGN OF BUILDINGS FOR AREAS OF THE EXTREME NORTH

Gosstroyizdat
1961

Scientific Editor, Candidate of Architecture

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This book has for its subject the know-how gained in designing and constructing buildings under the complex engineering and geological conditions of the Extreme North. It offers recommendations for designing and production of various building structures used successfullu for the erection of residential and industrial buildings on the permafrost grounds in the city of Noril'sk. It analyses the problems connected with reducing the cost of residential and industrial construction.

The book is intended for construction engineers, designers, and production workers engaged in construction in the areas of the Extreme North.

A. P. Kushnov

DESIGN OF BUILDINGS FOR AREAS
OF THE EXTREME NORTH

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DESIGN OF BUILDINGS FOR AREAS OF THE EXTREME NORTH

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INTRODUCTION

The northern and northeastern areas of the USSR occupy a large part of the country's territory and differ sharply from its central belt by a number of factors which affect substantially the living conditions of the population, construction methods, layouts, volume, design of buildings and structures, and also the special methods and requirements which are essential for performing the construction work.

Included among the natural features of these areas are: severe climate, grounds in permafrost state, winter winds of high velocity, snowdrifts, long winter season, polar day and polar night, and the inadequate development of the territory. The most typical feature in almost all of these areas is the presence of grounds in permafrost state.

A study of these features and their distribution over the territory made it possible to define the boundaries between the areas of the Extreme North and those of the Northeast (Fig. 1). The study was made by the Leningrad affiliate of the Academy of Construction and Architecture USSR working on the project for "Rules and Standards for Layouts and Buildings in the Populated Places Located in the Areas of the Extreme North and Northeast, USSR"

The conditions listed above, which make the planning and construction difficult, are far from being common over the huge territories of the Extreme North and Northeast. An example is the nature of the permafrost grounds. Their structure and thermo-physical and mechanical properties are different in different areas and also within the boundaries of the same construction sites. For example, the grounds in the area of Magadan and of the middle part of Kolyma consist mostly of gravel with insignificant inclusions of ice; this makes it possible to use conventional designs for buildings and structures. But the grounds encountered in the areas of the lower Ob', Yenisey, Lena, Taymir.Peninsula, Chukotka, etc. consist mostly of fine-grained soils in permafrost state containing excessive moisture and large inclusions of buried ice.

In the area of Yakutsk and Verkhoyansk, the temperatures during the winter drop to -60°, but the summer is comparatively long and warm. The difference between the highest and lowest temperatures during the year reaches 100 degrees; the winds are not strong and the layers of snow are rather small. But in the areas of Noril'sk, Dudinka, and at the coast of the Arctic Seas, while temperatures rarely reach the -50° or -55° level, snowstorms are the usual phenomenom there. The winds blow with a velocity of more than 40 meters per second. The snow piles make the construction and the use of structures so difficult, that the struggle against them is one of the principal tasks. In the zone of zero-range of temperatures, the thickness of the permafrost grounds in different areas and in different places of the same area has temperatures varying from 0° to -12°.

Fig. 1. The territory covered by the rules and standards for layouts and buildings in the populated places of the Extreme North and Northeast of the USSR

1) symbols: |||| the territory covered by the rules and standards;
____ boundaries of permafrost grounds;
.... boundaries of vegetation zones;
-.-.- boundaries of climatic zones.

These examples of the variety of the frozen-ground and climatic conditions demonstrate the impossibilty of using identical solutions for the design of buildings and structures and of using the same methods of organizing the construction. For the Extreme North, it is difficult to prepare typical projects, standards, and norms which do not require the solution of many complex problems for their application. Evidently it is expedient to divide the regions of the Extreme North and of the Northeast of the USSR into zones covering the territories with nearly the same frozen-ground and climatic conditions. This makes it possible to recommend for such zones the technical solutions which will assure reliable exploitation and economical design and construction for the structures.

However, the low temperatures lasting for 6-8 months, the permanent frozen state and, in many cases, the necessity of preserving the permafrost state makes it possible (with certain correctives) to use the technical solutions tested in the construction and exploitation of buildings in Noril'sk, Yakutsk, and in other regions.

With this in mind, the author describes the experience in designing and constructing the buildings of the Noril'sk Mining and Metallurgical Combine in the largest industrial center and the largest city of the Extreme North of the USSR -- the city of Noril'sk, where the designers and builders during the 20-year period of activity have found and are now finding technical solutions enabling them to build efficiently and comparatively economically buildings and structures on permanently frozen grounds. Of more importance is the fact that the durabilty of a predominant majority of the buildings in the areas of Noril'sk and Dudinka confirmed the correctness of the adopted technical solutions after the many years of their exploitation.

Except the TETs (Thermoelectric central station), where the designers handled the development of only certain parts of the project, all structures in Noril'sk and Dudinka were designed right there. During the entire time spent in designing and construction of the enterprises of the combine and of the city, no instructions for use of norms and no technical literature was published that could clarify the problems connected with design and construction at the Extreme North, except the instructions for design of ground beds and foundations (NiTU 118-54 [Standards and specifications). These instructions, however, contain many recommendations which are unacceptable for the physico-geographical and frozen-ground conditions of Noril'sk, which was one of the reasons for their revision at the present time. The designers and builders of Noril'sk reached the solutions presently used for structures and the methods of their construction after many years of search by analysing thoroughly the causes responsible for any deformation and defect in exploitation of the structures.

Due to his desire to warn designers and builders of repeating the errors, the author describes a large number of deformations and collapses which have taken place during the entire period of construction in Noril'sk and Dudinka.

In summing up the 20 years of experience in design and construction in Noril'sk, the author is including the technical solutions and certain construction problems connected with the use of widely known building materials (bricks, concrete, metal, etc.). Local production of building materials, however, is extremely expensive in the regions of the Extreme North and in many areas in which there are no rocky beds, sand, or clay, it is connected with extremely complex and expensive delivery from the nearest brick-manufacturung plants and

from places containing deposits of raw materials. Extremely difficult and very expensive is also the delivery to construction sites of other materials (cement, gypsum, lime, etc.) which are needed in large quantities.

The need of new materials possessing high strength and frost- and heat-resisting properties becomes apparent, especially in the areas of the Extreme North. Based on this type of materials, there should be created new types of structures, buildings, and construction methods that would make it possible to perform the work at low temperatures with a minimum waste of labor.

The effectiveness of new materials, particularly for contruction in the areas of the Extreme North, is illustrated by the following: in 1961, the roofs of Noril'sk industrial buildings were covered for the first time with sheets of ABAT (aluminum alloy, $\delta = 0.8$ mm) made in accordance with the AMTU 252-57 specifications. Under ordinary conditions, the use of such materials, compared with roofs covered by reinforced concrete plates and roofing paper, reduces the cost by 5 rubles 22 kopeks per covered sq. meter, or 1,630 rubles per each ton of employed corrugated aluminum alloy sheets [See Note]. In the city of Noril'sk, the use of corrugated aluminum alloy sheets, compared to roofs covered with precast reinforced concrete plates and roofing materials, reduces the cost by 7 rubles 60 kopeks per sq. meter or 2,350 rubles per each ton of corrugated alluminum alloy sheets.

([Note]: The prices here and below are those of 1961. The information is taken from the handbook: Types of structures for protecting roofs and walls of unheated industrial buildings made of corrugated aluminum alloy sheets, published by Gipromez in 1959.

The supporting structures were designed as required by the existing specifications. However, the specific operating conditions required for the structures (due to the presence of permafrost ground beds, low air temperatures, and long winter season) require essential correctives in the specifications for the design and performance of work on concrete, reinforced concrete, stone and reinforced stone, and metal structures. The coditions of the Extreme North were not adequately taken into account; this caused deformations and collapse of structural components, and even of buildings, the design of which was based on the existing specifications (see below).

In addition to the description of experience in designing buildings in Noril'sk, the book contains examples of favorable and unfavorable technical solutions employed in designing major buildings and structures in Dudinka, Yakutsk, Vorkuta, and other towns of the Extreme North.

Chapter I

GENERAL PLAN AND LAYOUT OF BUILDINGS

pp 8-32

1. Effect of frozen-soil characteristic on the general plan for industrial enterprises

The construction territory of the Noril'sk Combine is located in the zone of so-called mergings permafrost grounds whose beds, however, have different frozen-soil characteristics, such as:

a) outcroppings of rocks in form of separate tiny islands scattered over the territory of the Noril'sk area;

b) tiny islands of thawing soil located mostly in places adjacent to streams, rivers, and lakes;

c) large-skeleton sand and gravel grounds in loose and frozen state which are insignificantly saturated with ice and yield small sediments upon thawing;

d) ice-saturated sludgy soils containing sheets and films of ice; when thawed, the soil is deprived of its supporting capacity or forms a thin mass.

Any building can be located on any of the listed beds, even when the thermal and moisture conditions are most unfavorable for their use. However, on certain of these beds, it may increase significantly the construction cost and impose certain conditions that restrict the use of the building. But an efficient technical and economical solution can be obtained from the exact knowledge and efficient use of the engineering and geological features of the building sites in accordance with the technological requirements for the location of the enterprises, engineering, and transporting communications.

A complete solution of a general plan for the areas of the Extreme North is possible only when the work in preparing for the projected assignment is preceded by a detailed engineering and geological survey of the area. It is necessary to know the contours of the rock outcroppingd with the isolines of the surface of the deposited beds of rocks, detailed contours of the thawed beds and of the loose frozen soils, the distribution of ice films, etc. At the sections formed by ice-saturated grounds which yield large sediments or lose the supporting capacity upon thawing, it is necessary to determine by measurements the temperature in the bulk of the permafrost grounds, because it is of decisive importance when designing foundations for buildings and structures. It should be noted that under ordinary climatic conditions, such a detailed engineering-geological survey of the area is required (without investigating the temperature of the beds) only during the designing stage, and only for the structures located on the general plan.

In projecting general plans, and communications in particular, it is necessary to take into account the possibility of abrupt changes in the topography of the locations, which is typical in the regions of the Extreme North. New streams and ravines are formed within a very short time. This is due to a larged depth of seasonal thawing: from 0.3 - 0.5 meters when covered with moss to 2.5 - 3 meters for bare soils. The presence of large inclusions of ice in the increased thickness of seasonal thawing serves to form surface cavities which collect rainwater. The sifted sections contribute to the formation of streams which, by rapidly eroding the ice-saturated fine-grained rocks, form ravines in the course of 2-3 years. Such phenomena are particularly typical in the settlement of geologists located at the slope of the Imangdin mountains, where ravines several meters deep have been formed in sections passed by tractors. Abrupt formation of new streams and ravines have been observed in other places.

The change in topography of the surface, especially over the communication construction route, made it necessary to introduce substantial corrections in the designs and estimates prepared in accordance with the earlier obtained topographical data.

The well-timed detailed prospecting and exploration of the region of the Noril'sk ore and coal deposits made it possible to locate metallurgical plants and shops on rocky grounds and to create an efficient transportation system for moving the ore for further processing.

The surfaces of the rocky outcroppings located mostly at the slopes of mountains and elevations are greatly inclined. The limited number and sizes of the rocky sites made it necessary to make use of the mountain slopes and to use widely the cascade manner of locating the buildings. The concentration plant, for example, is located on a mountain slope; the distance between the building for coarse-crushing located on the upper part of the slope and the main building at its lower part is ~ 120 meters. All shops of the ore-concentrating plant are connected by covered transporting platforms with the freight moving from top downwards. The main building of the ore-concentrating plant is so located on the slope, that the concentrate in form of pulp moves by gravity in pipes to the plants for further processing. Here, the distance covered by the concentrate to the copper-smelting plant is about 7 kilometers. This fact made it necessary to locate the ore-concentrating shops of the plant on the sites of metallurgical plants.

A slope of a mountain was used also for locating a sintering plant (Fig. 2). Both the concentrate from the concentrating shops and the agglomerate are carried to the smelting furnaces by a conveyer in covered platforms. The cascade location of the shops made it possible to reduce their construction costs significantly without affecting the technological requirements.

The desire of having the mechanical-repair base of the combine near the principal consumers and communications made it necessary to reject the rocky ground for building the base and to locate the latter on permanently-frozen grounds.

A complete solution of a general plan for enterprises located in the regions of the Extreme North requires, in particular, a technical and economic basis which can bring about the full development of the enterprise. This is

due to the fact that the sites with bases making it possible to erect buildings at a minimum of cost (rocky outcroppings, thawed grounds, loosely-frozen grounds) are, as a rule, located in form of separate tiny islands of limited dimensions. In such a case, an unproven reservation of sites for a possible later expansion of the buildings may increase sharply the construction costs of other urgently-needed objects due to the necessity of locating these objects on separate larger, but frequently more remote, sections which is connected with increased communication distances and with handling of larger sites. However, if the planning does not provide for a possible further expansion of the buildings, it may make it impossible to increase the capacity of the operating enterprises and necessitate the construction of similar shops on other, frequently more remote, sites. The building of enterprises not taken into account by the original general plan will inavoidably result in disrupting the transportation system of the industrial region.

Fig. 2. A large sintering plant.
Method of locating the buildings.
(1) direction of the rocks.

In projecting a general plan for Noril'sk enterprises considerable attention was paid to the transportation system and efficient solutions have been found which took into consideration the technological, engineering, and geological conditions. However, the subsequent introduction into the composition of the combine of enterprises not included in the original plan (a plant for reinforced concrete products and commercial concrete, a shop for mineral fibers, concrete castings, warehouse structures, etc.) disrupted the transportation system and created a counter-movement of freight.

In designing the general outlay of the Noril'sk TETs (Thermoelectric Central Station) by taking into account the ultimate capacity determined by the I and II construction priorities, an exposed rocky site has been selected for the best location of the buildings (further development of the power base was planned by building a second TETs in another place). This made it possible to erect the main building on foundations laid low in depth by cutting off a little the rock in certain sections where the rock protruded above the level mark. The need, which appeared later, of expanding the existing TETs by adding the objects with III and IV priorities had for its result that the

buildings of priority IV required foundations of 25 meters in depth. It made the construction more difficult and increased the cost considerably. Yet, in front of the permanent main building where the auxiliary quarters are located, there is an unused leveled site with a rock protruding above the surface. This proves that the cost of construction could be significantly reduced by taking this fact into account at the time of planning for the ultimate capacity of the TETs.

2. Effect of climatic conditions in preparing the general plan for industrial enterprises

The polar night and the low position of the sun during the polar day, when the unsetting sun illuminates also the fronts of the buildings oriented towards the north, in many cases make it advisable to abandon the customary orientation of the buildings in the direction of the light in favor of other factors. Strong winds during the winter season and the low temperatures make it inadvisable to construct building entrances at the windy side. The buildings should be so located that a calm zone should be created on the territory of the yards and of the open operating sites.

Of special importance in the general plan for industrial enterprises and transportation facilities is to assure them with a minimum of piling of snow. Buildings contribute to the formation of snow piles which may paralize the transportation on the roads near the buildings and may cause difficulties and idleness in the work of the enterprise. The removal of snow from industrial enterprises is time-and-labor consuming and expensive. In Noril'sk, the annual cost of snow removal reached the sum of 4,300.000 rubles and the loss from the idleness of the enterprises caused by snow flurries amounted to 3-4,000.000 rubles per year. During the last few years, however, these costs have been considerably reduced by several measures taken for holding back the snow, by mechanizing the snow-removal work, etc. A correct solution of the problems connected with prevention of the territory from piling of snow is the main task when preparing the general plan and may help in many respects the operation of the enterprise. However, it is entirely impossible to avoid the formation of snow piles.

The operation of the intraplant transport during the winter season is connected with great difficulties. The railroad tracks and the roads for trucks passing along built-up areas are subjected to steady piling of snow. The mechanization of snow removal is frequently connected with difficulties. Particularly subjected to piling of snow are the roads and the railroad tracks passing along the windy side of the buildings. The design of the shop for electrolysis of nickel provided for building railroad tracks and an entrance at the northern (windy) side of the building. Already during the first year of operations piles of snow exceeding the height of the railroad rolling stock were responsible for the stoppages in the work of the nickel plant. Tens of persons using the transportation facilities struggled daily against the snow drifts, but even this did not assure a normal operation. Only the construction of a tambour (enclosure) adjoining the entire length of the building made it possible to operate the railroad transportation without interruptions (Fig. 3). The supporting structures of the tambour roof were designed to take care of possible precipitations of snow in order to eliminate the need of constant removal of snow from the roof.

Fig. 3. Nickel-electrolytic plant. Railroad entrance .

key: 1) main building; 2) heat-retaining curtain;
3) annexed tambour.
a) front view; b) view along 1-1 (prior to annexing the tambour); c) view along 2-2 (after annexing the tambour).

The experience of many years in operating the industrial enterprises, the time and labor spent in removal of snow, and its large annual costs made it necessary to devise a plan for protecting the industrial enterprises and the city of Noril'sk against snow drifts. The preliminary work included the necessary explorations to determine the main directions of snow drifts at different areas, the piling places of the snow, etc. Methods of holding back and stops for removal of snow have been developed for individual enterprises. The measures specified by the plan for protection against snow, although taken by a few enterprises, proved to be so effective that the general plan developed later also included a plan for protecting the territory against snow and the cost of its fulfillment was incleded in the estimated cost of the enterprise.

3. Planning for populated places

The principle governing the location of individual buildings on sites having the best engineering-geological subsoil features and the resulting separation of individual enterprises removed from each other by several kilometers, while used in planning for industrial objects, is entirely unacceptable in planning for populated places.

In selecting the territory for building a city, the suitability of the territory must be judged not by the presence of individual sections possessing reliable types of subsoil (for example, rocky, loosely-frozen, and other grounds) suitable for erection of major buildings, but the entire territory must be evaluated. It is necessary to take into consideration that the durability of the buildings and of the communications can be assured when built on permanently-frozen grounds existing in solid state with individual inclusions of burried ice, provided that the conditions assuring the retention of the frozen state in the subsoil can be maintained during the construction and operation of the buildings and communications.

This not withstanding, in developing a plan for populated places it is best to use as much as possible individual outcroppings of rocks for the construction of monumental buildings. For example, in developing the plan for the city of Noril'sk, certain areas with outcroppings of rocks have been specified for the construction of 7-story buildings of Mining-Metallurgical Technikum, of the technical library, of the Party House of Education, etc. At the same time, many multy-story residential buildings were erected in a section filled with soil containing dust and silt in solid state and having sheets of ice and separated ice "films". When thawed, these soils become a diluted mass and lose entirely their supporting capacity. The territory adjacent to the southwestern part of the city and containing comparatively low deposits of rock was made into a park due to the large amount of work required for a vertical outlay; only at the apex of the hill was built a building for a swimming pool.

In selecting the outlay for cities and populated places it is necessary to take into account the factors which affect unfavorably the physical, and even the moral, state of the population of the regions of the Extreme North. It is the frequently occurring snow storms and severe frosts. A snow storm will rapidly form large piles of snow. During the first years of building the city of Noril'sk, two-story buildings were covered with snow reaching the level of the roof. The snow could not be removed in time. The buildings were entered by walking through tunnels made of snow. Pedestrians walking

during a snowstorm spent great efforts in overcoming the force of the wind. Moving from place to place has for its results pronounced fatigue, frequent colds, frostbites and, occasionally, serious injuries.

Even when winds are absent, severe frosts are frequently the cause of frostbites. The cold is particularly felt when the wind is strong. In the construction practice of Noril'sk a term known as "the weather severity" is used for regulating the work in open air. The weather severity is defined as the sum of the negative temperature of the air and double the velocity of the wind measured in meters per second. No construction work is performed in open air when the weather severity exceeds 45, which corresponds to an air temperature of -25° and a wind velocity of 10 meters per second. However, the weather severity index frequently reaches the 80 and even the 100 level; under such conditions pedestrians must move even when accompanied with children of pre-school age. Sudden changes in weather during the winter are especially unhealthy for old people or for persons with heart conditions.

During the day the temperature may drop by 25° and the wind velocity may change from complete calm to a velocity exceeding 40 meters per second. Climatic changes are accompanied by abrupt changes in atmospheric pressure. The unfavorable effect of climatic factors on the population can be reduced by shortening the routes used by pedestrians and, for this purpose, in planning for both tiny places and cities as a whole, it is necessary to stress compactness in preparing the general plan.

In selecting the area for building a city under the conditions of the Extreme North it is necessary to to strive to have the area as near as possible to producing enterprises and to make it convenient for the labor force to travel during the snowstorms. Frequent interruptions in transportation are possible during the snowstorms due to both the piling of snow and lack of visibility. In Noril'sk, despite the presence of electrified railroad lines to the suburbs, it is still necessary at the mining enterprises located in a radius of 10-20 kilometers to create residential settlements for placing the essential staff of workers.

The disposition of cities and populated places on a territory made up of permanently frozen subsoils requires large capital investments for improving the building sites. The work for laying well-arranged underground communications is especially time-and-labor consuming and requires large expenditures. The need for keeping the subsoil in a frozen state increases sharply the cost of foundations under the buildings. These expenditures can be reduced by a general plan which emphasizes compactness to be accomplished by building 4-5-story houses. As an example, a comparison is made between two versions of buildings used for one of the blocks of the city of Noril'sk.

Version I. Building of 5-story brick houses.

Version II. Building of standard 2-story wooden houses.

The area required per 1000 sq. meters of residential ground, including the territory built-up with houses for cultural and general services, is equal to 0.212 hectares according to the first version and to 0.625 hectares according to the second version. The work done for building in height, conveniences, and engineering communications costs 190,000 rubles per 1 hectare of built-up area. The cost per 1000 sq. meters of residential area containing 5-story

brick houses is 41,000 rubles higher than for 2-story wooden homes. The saving resulting from less work in vertical building, conveniences, and engineering utilities is: (0.625 - 0.212) x 190,000 $\approx$ 79,500 rubles, i.e., the use of wooden buildings increases the cost by 37,500 rubles per 1000 sq. meters of residential area. This fact is the one which determined the number of stories (5-story) used for building up the city of Noril'sk. Still more economical would be the building of 6-7 stories in height, but the need of constructing and operating of elevators, as well as the working conditions in erecting structures during the winter made it advisable to provide the city with 5-story residential buildings.

In planning the layout for cities of the Extreme North it should be taken into consideration that in many regions no territory should be allotted for growing vegetables. Despite the many years of attempts to plant trees and brushwood on the territory of the city of Noril'sk, except the annual planting of oats and hothouse flowers, there is practically no vegetation in the city. Therefore, it is not advisable to increase everywhere the city territory by using large section for growing vegetables. It is necessary to take into account that an increased territory, in addition to raising the cost of construction, will also increase the cost of removal and carting away the snow.

These factors, which are related to the engineering-geological and climatic conditions, served as a basis for selecting the territory and for planning the layout of the city of Noril'sk. Consideration was given to six potential areas which could satisfy the requirements for the layout of the city. The selected area is located to the northeast of the lake Dolgoye. This area, which is made up of solidly frozen subsoil with individual sections of rock outcroppings, made it possible by adhering to certain conditions to erect major buildings and enginnering communications. The sections located at the southeastern part of the selected area had grounds made up of dusty and silty soil with sheets of ice and their fitness for construction of major buildings was doubtful; for this reason, it was contemplated to locate there light-duty type of buildings.

The nearness of the city to the principal enterprises and the topography of the location made it possible to solve the problem of transporting the workers to the plants and mining enterprises by autos and railroads. The correctly determined direction of the predominant winds served to relieve the city of air pollution by the waste gases of the plants and of the thermoelectric central station (TETs). The nearness of the lake and building adjacent to it of a park and structures for sports provided the population with a place for rest.

In planning the city, the adopted layout provided for its protection against snowfalls. This is of particular importance, because enclosing the buildings with snow-protecting fences is insufficient to hold back the entire snowfall. Two types of layout are possible for solving this problem.

1. Through streets laid out along the predominant direction of the winter winds. This solution provides an unobstructed movement of snow along these streets, but it creates considerable difficulties for the population and does not prevent snow piling by winds with not predominant directions.

2. The use of the built objects as a snow and wind protecting device, because it was established that the main mass of the snow moves in a zone not higher than 5-10 meters. The planners did not arrive to this solution at once, but as a result of studying the accumulated experience with the streets

of the city of Noril'sk with buildings arranged in a conventional perimeter with open spaces between the houses.

Strong snowdrifts and the lack of wind-protected places inside these streets made them unsuitable for children's recreations and walks. These facts proved the unsuitability of conventional layouts for the city of Noril'sk. In addition, the buildings located separately inside the streets required substantial and economically unjustified work for supplying them with engineering communications. Therefore, after a study of the experience of the first few years of building, the revised original plan had a layout based on the following basic principles:

a) reduced number of streets and areas open to the action of the predominant winds;

b) increasing the length of the streets located at the side of the city exposed to winds (Fig. 4);

c) using as much as possible closed contours in building up the streets. Covering the inter-street spaces with buildings adjoining the outside contour of the street block (Fig. 5) which makes it possible to bring all engineering communications through ventilated cellars of the buildings.

The accumulated experience of industrial construction in cities, including also the city of Noril'sk, made it recently to introduce substantial changes in the plans for building up a city. First, it became necessary to use for residential building component parts as much as possible by reducing to a minimum the list of building parts. This made it necessary to abandon the use of individual plans with front views of complex configuration. The employment of large components made it necessary to introduce tower cranes in construction and to provide economically worthwhile facilities for transporting products and materials. In connection with this, only certain types of plans were used for the subsequent building of other street blocks.

The complexity and the very high cost of constructing of street headers for steam pipes, water pipes, sewage, and cable networks made it necessary to consolidate significantly the newly built-up street blocks. All of these circumstances made it practically necessary to review once more the plans for the unbuilt part of the city.

An entirely different principle is used in building up the cities of Yakutsk and Vorkuta, where the planning did not take into account the need of building later a all-city system of water supply, sewage, and other engineering communications. As a result, instead of a compact built up city as a whole and of compact street blocks, there is a dispersed built up of individual sections with two and three-story houses.

With the problem solved in this manner, the excessive length of street headers and of engineering communications, the large number of inlets to the buildings, and other work for the welfare of the city will lead to unjustified excessive expenditures. For Yakutsk, Vorkuta, and other cities located in regions with permanently-frozen grounds, it would be more expedient to build them up with new street blocks in accordance with plans based on the specific requirements for the regions of the Extreme North and of the Northeast of the USSR.

Fig. 4. Method of building up a part of the city of Noril'sk

Fig. 5. Layout of Noril'sk street block No 29
Кв = street block.

4. Effect of subsoil grounds and climatic conditions on the volume-planning of industrial buildings

The high cost of work spent on foundations, outdoor utilities, and conveniences makes it an all cases expedient to strive to reduce the territory of the enterprise and particularly the area to be covered with buildings. Most economical would be the erection of multi-story industrial buildings.

In planning the Noril'sk ore-concentration plant, the building for coarse crushing located on undisturbed rocky ground was built in form of a multi-story building of more than 36 meters of overall height (Fig. 6). The high-power crushers and screens were installed on the roofs of the upper floors. Such an arrangement of the building is in accordance with the requirements of the technology. The ore for subsequent processing is made to enter by gravity. This reduced significantly the cost of construction and of operating the shop. It should be borne in mind, however, that not all types of subsoils of the regions of the Extreme North can provide stability of multi-story buildings without large expenditures for their reinforcement. In planning for buildings on grounds which may become greatly sagged when the enterprise is in operation, it is expedient to use buildings of no more than 1-2 stories in height.

Fig. 6. Sectional view of building for coarse-crushing of the Noril'sk ore-concentration plant

The desire to locate the structures on grounds which can assure their durability in operation made it in a number of cases to layout the buildings depending on the features of the grounds. Thus, for example, in the case of sloping outcroppings of rocks used for foundations, in a number of cases it was necessary to subdivide the buildings into individual units located in cascade along the slope and connected by closed transporting facilities, or to design them with a shape that would require a minimum of work for a vertical outlay and for building the foundations.

Still, even by using the best layout for the buildings of the industrial enterprises on the rocky areas of the city of Noril'sk, the desire to install foundations by avoiding unusually large depths met with no success. For example, the foundation for the electrolytic shop was installed to a depth of 20 meters which exceeded the height of the building. In the electric furnace department of the nickel plant and in the building containing the electric filters, the foundations are laid to a depth of 16-18 meters, while in the main building of the TETs, the depth is 25 meters, etc.

The layout and the orientation of buildings in direction of light were affected to a considerable degree by the limited size of the area occupied by the coke and chemical plant located on thawed grounds; also by the limited size of the areas of the Noril'sk mechanical plant and auto base made up of loose frozen grounds.

Snowdrifts affect substantially not only the fulfillment of the general plan, but also the volume-planning for the buildings. The first requirement is the need of covering the warehouse area, which under ordinary conditions is expedient to be left uncovered. For example, the metal warehouse of the Noril'sk mechanical plant is built uncovered and located between two buildings. The snowstorms during the winter pile up snow to a height reaching the stacks of the kept metal. It is not possible to mechanize the removal of the packed snow. Although a large number of people are busy during the long winter in removing the snow from the warehouse, yet it is frequently impossible to find the needed blank or part before the arrival of the spring thaw. The cost of building a covered metal warehouse could be returned within 4-5 years of operation. A similar wrong execution was allowed to take place in planning of other uncovered warehouses, namely, the molding box warehouse of the mechanical plant, the warehouse of finished products of the reinforced concrete plant, and others, which resulted in excessively large operating expenses and, occasionally, in forced stoppages of work.

The large piling of snow and the limited ability of working with bridge, tower, and gantry cranes at the warehouse areas with the velocity of wind exceeding 12-15 meters per second (taking place from 80 to 120 days of the year) made it necessary to build the next warehouses mainly of the covered type.

The operation of industrial enterprises lasting for many years disclosed several essential defects in the layout of buildings built in accordance with designs which are typical for regions of the central climatic zone. The Noril'sk mechanical plant, for example, was built in 1940-1948 in form of individual buildings located in parallel rows extending up to 150 meters (Fig. 7).

Parts for subsequent machining were delivered from shop to shop by railroads, i.e., they were loaded into the cars, transported to the railroad station from which they were delivered to the other shop. During a snowstorm with piles of snow, such a procedure last several days. Opening of doors to admit the rolling stock resulted in abrupt cooling and formation of vapors in the shops. The open space between buildings was used due to the existing norms for natural illumination of the buildings. But the presence of windows did not eliminate the need for artificial illumination during the entire year. In addition, such a layout for the buildings lead to an ineffective use of the high-quality grounds and increased construction costs spent for outdoor utilities and for the improvement of larger areas of the territory.

Fig. 7. Layout of shops of Noril'sk mechanical repair plant
a) built according to plans; 2) sample of
efficient layout of buildings.

The construction of the plant in form of separately located buildings was the result of underestimating the special conditions of the Extreme North by the designers. Without relying too much on natural illumination, the structures could have been combined into a single building. This would make it possible to reduce considerably the volume of outside walls, the number of foundations, the number of reinforced concrete structures of the building's shell, and to arrange the inter-shop transport without trips outside the building and to avoid large piles of snow between separate buildings.

Many enterprises in the city of Noril'sk have been built in form of separately located buildings, namely, the central base for automotive vehicles, the mechanical plant of the mining administration, etc.

At the present time, the planning follows the principle of maximum consolidation of buildings with the shops of the enterprises arranged in blocks. For example, the block of shops of the Kayyerkan coal mining pit, which is now under construction, combines into a single building a garage for 48 vehicles, an excavator repair shop, a mechanical repair shop, an electric repair shop, a substation, and a general service combine. The projected building for the block of shops of the open-cut mine combines the shop for repair of diesel-electric locomotives, the shop for repair of dump cars, the excavator repair shop, the shop for servicing boring bits, the mechanical repair shop, the electric repair shop, the spare-parts warehouse, a substation, and a general service combine. Such a consolidation of buildings into blocks of shops made it possible to reduce the construction cost by 25-30% and to improve significantly the operating conditions of the enterprises.

The consolidation of shops into a single building, however, makes it less possible to illuminate the inside rooms with natural daylight and impairs the conditions for natural ventilation. Conventional skylights (for air and light) provide neither illumination nor ventilation, as proven by the operating experience in Noril'sk. The adjustment of skylight-casements during strong winds and snowdrifts is impossible. Usual opening devices are unable to release the frozen casement. Even when open, all four of its parts and their connections become packed with compressed snow which prevents their closing. When open, the casements of the skylights contribute to the penetra-

tion into the shops of large masses of snow and cold air during a snowstorm. Wind gusts changing frequently their velocity and direction cause the air to whirl insided the buildings.

Complexity of operation and ineffectiveness of skylights for providing light and ventilation have for their results that, during the winter, a predominant majority of Noril'sk enterprises are tightly plugged and piled with snow (Fig. 8). Also, the presence of skylights in certain Noril'sk industrial buildings resulted in damaging the structures supporting the roofs.

Fig. 8. Section of mechanical repair shop. Snow piles on roof with lower level. 1) predominant wind.

Technical conditions require that, in determining the magnitude of the snow-load in places where a low building adjoins a taller one with a wall containing open spaces for air and light, the difference between the roof-levels should be equal to the distance from the bottom of the open spaces to the roof of the adjoining lower building. For this, the snow density is assummed to be equal tp 200 kilograms per cubic meter. The experience with roofs in Noril'sk shows that during a snowstorm with winds reaching a velocity of 40 meters/sec it is impossible to remove the snow from the roofs. Snowstorms frequently last for several days. All outdoor works and removal of snow from the roofs are discontinued when the wind's velocity exceeds 22 meters/sec. The snow quickly covers the roofs with lower level. It was found that the wind pressure can change the snow density from 0.22 to 0.55 kg/cu. meter and raise the snow piles to a height exceeding the bottom level of the windows in the wall above the roof of the lower building.

In heated buildings, the snow falling from the open skylight casements to the zone of warm air currents and also from the windows located above the roof of the lower building becomes melted and together with the condensed moisture of the air ejected through the skylight and the windows forms icicles on the lower roof. For example, large masses of compressed snow held back on the roof of lower level and in the skylights of the electrolyting shop of the nickel plant and of the TETs machine room are responsible for the intensive formation of ice deposits. At the TETs (Thermoelectric central station), the overloading of the roofs demolished a part of the precast reinforced concrete plates and, correspondingly, increased the load on the metal girders of the roof. The metal girders of the electrolyting shop were deformed to a degree that threatens their collapse.

In these cases, the collapse of the roofs was prevented by taking a few steps, such as, dismantling the skylight, reinforcing the metal girders of the electrolytic shop, and by adding other parts to the metal structures covering the machine room of the TETs in order to increase the supporting capacity of the precast reinforced concrete plates. This overloaded the metal covering structures by 20-30%.

Fig. 9. Roof of main building of large ore-concentration plant after a snowstorm. 1) deposited ice.

The use of roofs of different levels will ruin the roofing material and the insulation, as it occurred in the substation of the ore-concentration plant. The substation was built into the main building and was designed with a roof descending about 5 meters lower. The moist warm air entering from the shop through the open spaces in the descending wall formed under the large cover of snow an accumulation of water which was held back by the overhanging ice. This water was changed into ice by a drop in temperature (Fig. 9). The water penetrating through the roofing material into the heat-insulating layer of foamy cement had reduced its thermal resistance and intensified the melting of the snow. The pentration of water into the substation made the operation extremely difficult. Annual repairs of the roof produced no results. To eliminate this defect, it was decided to build a second cover with empty space between the roofs, the ventilation of which should prevent the melting of snow on the roof (Fig. 10).

An experimental roof with the wind blowing through the space between the skylights (Fig. 11) was built for the sintering shop of the nickel plant to eliminate snow piling on the lower roofs. It reduced considerably the piling of ice between the skylights, but the snow held back by the elevated part of the building reduced the amount of air and light passing through the skylights.

Large piles of snow overloading the outer span were formed on the roof of the electrolysis department of the electrolytic shop which had roofs of different levels. In planning the expansion of the shop, it was decided to remove the existing structures and build a roof with the same level. The newly designed roof had lateral air and light skylights located in parallel to the direction of the predominant winds (Fig. 12). It reduced considerably the snow deposits, but failed to illuminate and ventilate the inside of the building because it was impossible to adjust the casements of the skylights.

Fig. 10. Ore-concentration plant. Double above span of substation. key: 1) shafts; 2) read from top down: 1 layer of ruberoid over 2 layers of pergamyn (artificial parchment paper); cement tie piece; plates of precast reinforced concrete; cross pieces of precast reinforced concrete; brick column of 250 x 250 bricks, h = 2 bricks.

Fig. 11. Building of sintering shop. Ventilated roof between skylights. 1) through open spaces; 2) predominant winds.

Fig. 12. Nickel electrolyting shop, sectional view.
Priority I roofs are shown by broken lines.

Later, in designing the roofs, first under consideration was how to prevent the piling of snow and for this it was necessary to increase in a number of cases the building's volume by using so-called prolonged roof-slopes (Fig. 13). Design of individual spans without natural illumination was allowed to take place. At the present time, skylights with wind-protected shields (Fig. 14) are employed for ventilation of metallurgical shops subjected to large quantities of given off gases. The advantage of skylights with wind-repelling shields is that they do not require adjustments and their operation does not depend on the direction and velocity of the wind. They do not, however, eliminate snow piling and are unfit for natural illumination. Snow piling on roofs can be reduced by locating the housings with wind-repelling shields in parallel to the predominant winter winds, or by arranging them in form of individual shafts on the elevated part of the roof.

Fig. 13. Smelting and refining shop of the copper-smelting plant. Prolonged slope of roof.

The rooms of wide buildings can be illuminated by using smooth semi-transparent roofs. If built without abrupt change in levels, the snow will be blown off such roofs and it will be easy to remove the settled dust. Transparent sections of the roof should be made of strong unbreakable plastics suitable for airtight joints.

The experience of many years in dealing with roofs has shown that in the absence of abrupt level changes the snow is not retained on smooth or spherical

roofs; the snow fallen during calm weather is blown off by the first snowstorm. It made it possible in designing such roofs to assume a snow-load of 0.5 R_s which was used in specifications prior to the year of 1955. Without taking into account the open spaces in the walls of the adjoining building, the regularity with which snow piles are formed on roofs with lower levels and the increased density of snow at places where it accumulates furnished the basis for using the SNiP instructions in figuring the snow-load at places where the buildings drop in height. But actual data should be used in figuring the snow density. Concerning Noril'sk, these deviations from the norms and existing specifications are agreeble to the Gosstroy USSR. In addition, the use of different levels for light and ventilation housings causes the formation of large deposits of ice in form of huge icicles settling on the cornices when the roofs are subjected to the direct action of the sunrays (Fig. 15).

Fig. 14. Wind-protected ventilation skylights

Fig. 15. Formation of icicles on roofs of lower level

In designing industrial buildings, special attention should be paid to the design of the doors for entering railroads and trucks. It is very important to locate the doors by taking into account the predominant direction of the winds and to use a correct door-opening system and a correct heat-protecting system for the open space of the door.

Even in the absence of winds, the opening of doors in the nickel and copper plants produced a strong current of cold air caused by the ventilation and the gases exhausted from the furnaces which rarefied to a certain extent the air inside the buildings. The inability of keeping the closed doors airtight results in a movement of cold masses of air near the open space which is responsible for workers catching colds. Even greater troubles are possible when doors are opened manually during a snowstorm which, when done by inexperienced people, can result in serious injuries. During a snowstorm, vast masses of cold air and snow burst into the shop through the open doors.

More difficult is to solve the problem of designing doors for heated buildings filled with high content of moisture, especially for entering of trains. For example, the entrance of railroad rolling stock formed such a dense fog in the working area of the electrolytic shop that the visibilty extended to no more than 1-2 meters. The necessity of opening the door several times a day during severe frosts made the working conditions difficult and there were cases of injuries. Moreover, ice was deposited on the walls of the entrance which ruined the walls and the carcass of the building (the bricks of the walls became laminated and disintegrated). A high-duty heat-curtain was was built near the entrance, but even this did not solve the problem, especially during a snowstorm. Only by building a tambour so that the doors to the shop are opened only when the tambour door is closed and by using high-duty heat-curtains at both the tambour and shop entrances it was possible to avoid the formation of fog and prevent the building from disintegration.

A similar phenomenom was also the case at the entrance of the TETs machine room during the construction and assembly work for the expansion of the station.

In the heated shops of the mechanical repair plant the doors for the entrance of railroads have neither tambours nor heat-curtains, but there is a lesser penetration of cold air into the building. This is due to the fact that the fronts of the shop containing the doors are arranged in parallel to the predominant direction of the winds; it reduces the extent of the snow-affected section of the path in front of the entrance and the possibility of cold air blown into the shop during a snowstorm.

The unfavorable effect of opening of doors on the working conditions in the buildings can be reduced by taking the following steps.

1. In designing the ventilation of unheated buildings it is necessary to provide conditions that will prevent the rarefaction of air in the buildings. In unheated buildings, where the technological process is unavoidably connected with removal of gases and dust and requires an exhausting system, a forced ventilation supplying the building with warmed air must be provided in all cases. From the experience with unheated buildings in the city of Noril'sk (several shops of metallurgical plants) equipped with exhausting ventilation, it was established that best conditions for workers can be

obtained by an inflow of warm air through slits in the channels located at the lower part of the door's opening (Fig. 16). In such a case, a certain warming up is felt at a section adjoining a closed door and, when the door is opened, the warm air propels the cold air upward , reducing thereby the bad effect of the latter on the workers.

Fig. 16. Installation of heat-curtains for buildings
a) front view; b) view along 1-1; c) view along a-a;
key: 1) heater; 2) installed heat-curtain.

It is desirable to combine into one block the control regulating the the devices of the ventilation chamber with the mechanism for opening of the doors in such a manner, that with doors open there should be a more intensive pumping of warm air into the channel of the heat-curtain. The equipping of doors of unheated Noril'sk buildings with curtains was always accompanied with airtight sealing of the fencing structures of the building. The walls were made thicker by plastering, part of the windows were covered with bricks, etc.

2. The entrances should be so oriented as to have the walls containing the doors in parallel with the direction of the predominant winds. This can prevent the piling of snow on the entering path and reduce the blowing of the bulk of cold air into the building.

3. The door-opening should be inside the building or should be moving apart; the opening of doors on the outside is impossible even when the snow piling is insignificant. For doors opening inside the shop and for a dead-end railroad entrance, the length of the part of the path inside the shop should be increased by the width of the door. The doors for the entrance of rail-

road cars (desirable also for trucks) should be opened by mechanisms.

4. For heated buildings are recommended heat-curtains. Buildings with a high content of moisture should be equipped with warmed tambours and high-duty heat-curtains.

By effecting the listed steps, it was possible to create in Noril'sk normal working conditions in shops equipped with entrances.

Chapter II

SPECIAL DESIGN FEATURES CALLED FOR BY THE NATURE OF THE GROUNDS FOR FOUNDATIONS

pp 33-84

1. Requirements affecting the design

The following requirements must be satisfied when designing buildings for the regions of the Extreme North.

1. Assured durability of the buildings scheduled to be constructed in the zone of permanently frozen subsoils and instructions emphasizing the necessity of maintaining the planned operating conditions (it concerns the effect on the subsoil temperatures by the heat emitted by the buildings).

2. The possibility of erecting buildings when temperatures are low by taking into account the long duration of the winter season which, in many cases, makes it necessary to put a building into operation and to start the construction of the entire planned object prior to the arrival of the spring-summer thawing of the concrete and mortar.

3. The materials for the supporting and enclosing structures are to be accepted after a detailed economic investigation to ascertain the possibility of establishing a transporting communication system between the construction sites and the rail and water systems; the materials are to be selected by taking into account the minimum labor required for their production into finished products at the site of construction.

It was established by an economic analysis that the actual cost per man is 3.2 times higher in Noril'sk than in the regions of the central belt of the country. Taking into account the bonuses paid in the North, the wages of construction workers are 2.4 times higher than in other regions. Hence the extremely high cost of producing construction materials and products. Even in Noril'sk despite its developed base of a construction industry, in many cases it is cheaper to purchase construction materials elsewhere than to produce them in Noril'sk. For brick structures, however, it is more profitable to produce the bricks in Noril'sk (which ordinarily is very uneconomical in view of the conditions of the Extreme North).

The cost of local and important construction materials and products are compared in Table 1.

Table 1

Comparative cost of certain building materials and products (local and imported) in Noril'sk

key: 1) Name of material and product; 2) unit of measurement; 3) price in Krasnoyarsk, rubles; 4) cost of transporting from Krasnoyarsk to Noril'sk, rubles; 5) cost of imported materials and products, rubles; 6) price in Noril'sk; 7) extra cost when produced locally, in rubles; 8) M 100 building bricks; 9) reinforced concrete corrugated plates; 10) piles, 300 mm in diameter; 11) skeleton metal columns weighing more than 5 tons; 12) building girders with span from 24 to 36 meters; 13) lime, construction type; 14) window blocks; 15) door blocks; 16) boards for covering clean floors; 17) plates of foamy cement; 18) cement-fibrolite plates; 19) ferrous bolts and nuts; 20) M 400 cement; 21) pieces.

4. Giving consideration to the high cost of building and to the forced interuptions of construction caused by severe frosts and snowstorms which complicate the outdoor work and affect unfavorably the human organism, it is still necessary to try to reduce the cost of labor spent in erecting the selected structures. It is necessary to use supporting structures made of steel and of high-strength and light-weight alloys; for enclosing structures it is necessary to use light and strong materials. The production of structures made

of new material should be established in the regions connected with the construction sites of the Extreme North by marine, river, and railroad communications. The finished products should be delivered to the construction site in form of assembled components and panels.

5. In selecting the type of construction it is necessary to take into account the possible deformation of the structures caused by settling of the foundations when the buildings are in operation, particularly the settling of foundations installed on rocky and loose frozen subsoils; a number of other factors should also be taken into account.

The lack of knowledge of the features of construction work which are specific for the conditions of the Extreme North and for permanently frozen grounds is responsible for the several grave errors made by the designers during the initial period of construction in Noril'sk which resulted in deformation and, in certain cases, to the collapse of the buildings. A study of all cases of deformation and collapse of buildings and communications which have taken place made it possible to improve gradually the technical solutions and to find new ways of erecting complex structures on different types of grounds in the region of merging permanently-frozen grounds; also to make the structures durable and to satisfy the required operating conditions.

The basic factor which determines the construction solution for a building is the the frozen-ground characteristic of the soil; with this as a basis, the design of buildings is subdivided into the following typical groups:

a) buildings erected on rocky grounds;

b) buildings erected on thawed , or preliminarily thawed grounds;

c) buildings erected on permanently-frozen grounds by taking into account a subsequent thawing and development of sagging;

d) buildings erected on grounds remaining in the permanently frozen state.

Given below is a description of the deformations and collapse of buildings and structures that have taken place when erected on different types of grounds and also an analysis of the causes responsible for it; this makes it possible to benefit from the errors made in construction in Noril'sk and in other cities and to avoid a repetition when designing under similar conditions.

2. Buildings erected on rocky grounds

Supporting Structures

In Noril'sk, on rocky grounds are erected: an ore-concentration plant, a nickel, copper, and cobalt plants, the TETs (Thermoelectric Central Station), and certain buildings of the mining ditricts. The supporting structures of the buildings erected on rocky grounds did not differ from the usual designs. Even here, however, there are certain features the disregard of which resulted in deformation of certain buildings, such as of the mechanical shops of the mine No 7/9 and of the copper-smelting plant, the buildings of the fire-prevention and diesel-electric stations of the "Medvezhiy Ruchey" mine, etc. The loads on the foundations of these buildings were insignificant and could not demolish

the rocks. The buildings, however, became so deformed that restoration work was necessary, while the building of the fire station collapsed entirely.

Fig. 17. Deformed building of the fire station

The building of the fire station was planned to be erected on a rocky ground. In view of the small load, the foundations were installed on the cracked upper layer of the rock which, under ordinary conditions, is entirely permissible; but the builders did not take into account the ice saturated in the cracks. As a result, at the expiration of several years, the soil under the building had softened to a considerable depth and caused the sagging of the foundations (Fig. 17). An investigation proved that the layer of the demolished rock reached 3-4 meters in the foundation. The thawing of the ice inclusions in the demolished layer caused a large sagging of the foundations. The deformations of the buildings of the mechanical shops are due to the same causes.

In the majority of cases the thickness of the layer of demolished rock filled with ice was insignificant and by deepening somewhat the foot of the foundations the could be made to rest on a strong rock. At times this would also be advisable from the economic standpoint, because it would make it possible to increase the pressure on the base and reduce thereby the foot of of the foundations. In building, for example, the I and II priorities of the Noril'sk TETs the pressure on the rocky base was allowed to reach 20 kilograms per sq. centimeter with consideration given to the cracked state. In building the III-priority of the TETs, the pits under the foundations reached a depth of 25 meters and it was economicaly expedient to deepen further the pits by removing 2-3 meters of cracked rocks and increase thereby the calculated resistance of the base to 40-50 kg/cm^2. This made it possible to reduce the volume of excavation work and to reduce significantly the cross section of the foundation feet.

Such a solution, however, is not always advisable because the demolished rock may be extended to a considerable depth. The durability of buildings

erected on cracked, ice-saturated rocky beds can be assured by using the technical solutions recommended for buildings to be erected on permanently frozen grounds with consideration given to their subsequent thawing and possible sagging.

In certain cases it is expedient to increase the density of the bases by preliminary thawing. For this purpose, steam under a gage pressure of 6-8 atmospheres is injected into the holes drilled to the depth of the disrupted rock layer. After 6-8 hours of steaming, the thawing extends to a radius of 1.5-2 meters. The weight of the ground causes the base to sag and to become partly more compressed.

In erecting particularly important buildings on frozen, cracked rocky grounds when irregular sagging is not permitted, the base can be reinforced by the injection method. For example, in designing the building above the Noril'sk mine No 7-bis together with a reinforced concrete pile driver for the vertical shaft, a geological investigation had established that a demolished layer of rock containing cracks filled with ice inclusions extends to a depth of up to 30 meters. The technologists were confronted with rigid requirements, namely, the building must be airtight to enable the creation of rarefied air inside the pile driver. The latter is connected with the devices of the lifting and transporting equipment and a deviation from the vertical axis of the pile driver was not permitted. In designing the shaft it was necessary to make it possible to use the shaft for ventilation purposes and for passing large quantities of warmed air.

The execution of the last requirement was connected with an invoidable thawing of the bulk of rocks adjoining the perimeter of the shaft. The sagging of the strata due to the thawing could cause considerable deformation of the pile driver and of the shaft also; this would disrupt the airtightness of the building and could distort its vertical axis. The apprehensions of the designers were based on the serious deformations of the shaft of the building above the Vorkuta mine No 27 which was built on permanently frozen grounds. The shaft was ruined as a result of the thawing of the adjoining bulk of permanently frozen ground, which was caused by the passage through the shaft of large quantities of warm air.

Taking all this into account, the designers provided for strengthening the base by injecting cement mortar. This method of strengthening was accomplished successfully for several Noril'sk objects. The injection was effected through holes of 15-20 centimeters in diameter drilled over the entire depth of the ice-saturated cracked rock. The location of the holes was planned for an injection radius of up to 1.5 meters. The steam pumped into the holes had a gage pressure of 6-8 atmospheres. The steaming time was determined by the complete thawing of the ice inclusions and by the warming of the bulk of demolished rock to a temperature of 40-50 degrees. The cement mortar was injected immediately following the steaming and the next hole was used for removing the formed water and for observing the radius of penetration of the injected mortar.

The warming of the injected base enables the mortar to acquire the required strength prior to the cooling of the bulk of rocks (Fig. 18). In certain cases the durability of a building erected on a rocky base is affected by the layer of the permafrost grounds located on top of the rocks which,

due to thawing, may bring about loads which are usually unaccounted for. For example, several heated buildings, mostly of the temporary and light-weight type, built on rocks extending 3-5 meters in depth became deformed after several years of operation and certain of them were demolished by landslides. Prior to that, no landslides were observed during the seasonal thawing of the grounds; they appeared as a result of the presence of a large thawing bowl.

Fig. 18. Mine No 7-bis. Reinforced concrete pile driver and the building above the mine. Methods of cementing the base: 1) holes for cementing the base; 2) border of cemented zone; 3) surface of the rock.

There is a possibility of large horizontal forces appearing due to the swelling of the layer of soil above the rocks during the winter freezing. For example, a formation of cracks during the winter was observed in the walls of the underground channels which were caused by the horizontal forces of the swelling. The calculation of the lateral pressure on the ground by the enclosing walls without taking into account the forces due to swelling had shown in this case that the stress in the walls was only insignificant.

During the seasonal freezing of an active layer, the forces due to swelling destroyed the concrete foundations for the construction of the administration building at the Gvardeyskiy Square of the city of Noril'sk. The

construction of the building was discontinued following the erection of the foundations on rocky grounds and the digging of trenches under the channel for communications. Three years later, upon the renewal of the work it was found that the axes and the marks for the top of the foundations were displaced. With these foundations uncovered it was established that the forces due to swelling broke the concrete foundation columns (mostly along the concreted seams), raised them by 10-15 cm, and moved them aside.

A particularly pronounced action of the forces due to swelling on the deformation of buildings can be observed in the building for cleaning purposes. The construction of this building began in 1950. The construction of the building was temporarily discontinued following the erection of the carcass whose columns on one side rested on a rock and, on the other side, on a supporting wall. Upon resuming the work several years later it was discovered that the supporting wall was displaced to a considerable extent. Crack appeared on both the wall and on the columns of the carcass (Fig. 19)

Fig. 19. Deformation of the supporting wall of the building for cleaning purposes.

To prevent the building from collapsing it was necessary to replace the swollen grounds won non-swollen soil along the entire supporting wall, to convert into monoliths the precast reinforced concrete coversinside the building, and to transfer the cross-ties to the reinforced concrete reservoirs.

Different methods can be recommended for avoiding the injurous effects caused by the seasonal freezing of swollen soil above the rocks which affect the durability of the supporting structures of a building. One of those may be the partial or complete replacement of the layer of swollen soil above the rock with a non-swollen layer. At times it is more advisable to inrease correspondingly the strength or the durability of the structures; in many cases, however, no data is available for determining the horizontal forces due to swelling.

In designing buildings to be erected on a deeply (from 10 to 25 meters) submerged base, the zero-cycle of work reaches up to 30% of the cost of the building and, therefore, it is advisable to increase to a maximum the building spans. A widespread network of foundations makes it possible to use to a full extent the supporting capacity of rock deposits and of the reinforced concrete foundations and to reduce considerably the volume of the excessively labor-consuming excavation work. It should be stated that at the present time there are still unavailable mechanisms for developing frozen grounds.

The spreading of the foundations makes it necessary to use specific solutions for the design. As an example is the solution for the design of the building of a block of shops (Fig. 20) in Kayyerkan (district of Noril'sk). The building of the block of shops is buing built on a section having a rocky base deposited to a depth of 15-18 meters. The use as a base of the thick layer of grounds above the rocks in accordance with the method of retaining their permanently frozen state turned out to be unprofitable, because it would make it necessary to build a ventilated basement under the building. The loads caused by the 25-ton trucks and excavators are so large that the volume of work required for building a ceiling over the ventilated basement would have increased considerably the total cost of the building. In order to reduce the volume of the labor-consuming and expensive work in excavating the foundation pits, the building was designed with the foundation spacings enlarged to 18 meters.

Such an usual spacing of the foundations was made possible by the use of unusual solutions for the supporting and enclosing structures of the building. The roof of the building was designed with self-supporting, pre-shrunk panels with aluminum-alloy covers. The carcass columns, just as the foundations, are made of reinforced concrete monoliths with a spacing of 18 meters. The beams carrying the load from the walls are made in form of cantilever beams which made it possible to reduce the bending moment in the spans. At this, these beams serve also as supporting walls of the ventilation channels. The latticed metal beams under the cranes have a pan of 18 meters.

Such a solution in designing the supporting and enclosing structures made it possible to reduce considerably the cost and the labor spent in erecting the building and to fully utilize the supporting capacity of the rocky base of of the reinforced concrete structures of the foundations and carcass. The defect of such a solution is the larger volume of monolithic concrete due to the wider spacing of the building foundations.

A similar solution was adopted for several buildings under construction on deeply deposited rocky bases. For example, a 12-meter foundation spacing and a 32-meter enclosing span was adopted for a garage with 108 buses; a 12-meter foundation spacing was adopted for enlarging the anodizing department of the nickel plant, etc.

Fig. 20. Locating a complex of mining enterprises into a single building. a) plan on the $\pm$ 0.0 mark; 1) parking space for 48 MAZ-525 motor vehicles; 2) shed for repairing excavators and drilling rigs; 3) forging and welding department; 4) electric repairing with machine tools and handwork; 5) transformer substation No 2; 6) general service combine; 7) transformer substation No 1; 8) oil storage. b) section along 2-2; c) section along 1-1.

Floor and basement communications

Assured durability of the building's supporting structures installed on a rocky base does not yet solve all problems connected with the future normal use of the building. Specifically required for the regions of permanently frozen grounds is the construction of floors, foundations under the equipment, ventilation channels, and of engineering networks.

The rocky surface within the boundaries of the building are frequently covered by permanently frozen graounds which in certain cases are deposited to a depth of 20-25 meters. Under a heated building, such grounds are inevitably subjected to thawing. An irregular sagging and destroyed floors come as a result, depending on the irregular thermal effect of the communications, temperature and moisture conditions in the buildings, and on the topography of the surface of the rocks. Destruction of the inside engineering communications also takes place in certain cases.

In planning to erect the the electrolytic shop of the nickel plant on a site where the layer of permanently-frozen grounds covering the rock varied in thickness from 3 to 20 meters, in view of the inavoidable large quantities of warm "technological waters" (solutions) falling on the floor of the cleaning department, the area marked for the floor was provided with a reinforced concrete cover resting on foundations erected on a rocky base. On the cover was installed light-weight equipment and intershop engineering networks. The heavy technological equipment was installed on foundations erected on the rock.

In the electrolytic department, where the rock deposits reached a depth of 12-13 meters from the floor level, the falling of warm technological waters was assumed to be only incidental, therefore, use was made of asphalt floors covering a layer of concrete laid out on the ground. Ventilation channels for supplying warm air were installed in the floor along the entire shop.

In order to prevent the deformation of the outdoor engineering networks, a reinforced concrete channel resting on the foundation cantilevers of the building was provided by the design. The foundations for the light and auxiliary equipment (ventilators, pumps, etc.) were installed on the permanently-frozen grounds covering the rock. In case of sagging due to thawed ground, provision was made for a subsequent leveling of the equipment after the deformation of the foundations is ended. A special solution was adopted for the problem connected with the installation of the reinforced concrete electrolytic baths. Their installation directly on the rocks would have required large capital expenditures and extremely time-and-labor consuming construction. The planning took under consideration three basic versions.

1. Baths installed on separately located foundations erected on a rocky base.

2. Foundations resting on the permanently-frozen ground covering the rocks. Since it was necessary to hold the baths on a same level and to keep the sides in a stricktly horizontal position, and also to provide the baths with connections to the communications, it was planned to install pads under the baths which would make it possible to raise and level them easily.

3. Construction of baths on 3-pivot reinforced concrete arches resting on the foundations of the building (Fig. 21).

The third version was chosen as the most economical and the one which avoids sagging during the thawing of the layer of grounds above the rock. The shop began its operations in 1943 and, as early as one year later, the sagging of the floors was so extensive that it put out of order the ventilation system, the channels for draining the water, and other communications installed in the floor. The foundations of the ventilation chambers and for the fans sagged by up to 1 meter; it destroyed the chambers which were rebuilt by installing them on the existing foundations of the building (Fig. 22).

During the following years the floors and communications had to be repeatedly restored, but at the expiration of a short operating period they were again destroyed. To assure a normal use of the building, there were designed overhead structures of reinforced concrete to support the equipment, channels, floors, and communications.

Later, in designing buildings on deeply deposited rocky bases, the floors and communications were suspended on supporting structures resting on

a rocky base. In this case, a continuous reinforced concrete cover can be installed wherever necessary to support the light-weight equipment and communications. To the cover are suspended the channels and the pipes. For example, a continuous reinforced concrete cover was designed for the right span of the plant making reinforced concrete products. (Fig. 23).

Fig. 21. Nickel electrolytic shop. Sectional view of electrolytic department
1) original version of installing the baths; 2) the effected construction (the electrolytic baths installed on concrete 3-pivot arches resting on main foundations); 3) concrete-filled foundations.

There is, however, no need for excessive expenditures on sections where the sagging of floors does not disrupt the technological process. In such a case it is sufficient to prevent the sagging of individual foundations under the equipment and communications by installing the latter on structures erected on a rocky base. As an example is the solution for the left span of the same building of the plant for reinforced concrete products. The erection of all equipment-foundations directly on a deeply-deposited (10-15 meters) rocky base proved to be economically expedient. More economical proved to be the structure in form of a lateral cross bar resting on the foundations of the building and of specially erected row of columnar foundation in the middle. Located on the cross bar are the foundations under the units, the underground channels, and communications. The floor is made of assembled plates which can be readily relaid after extensive irregular saggings with the aid of the bridge crane serving the span. On the foundations of the building is also suspended the outdoor channel-header in which are laid out the warm-water, electrical communication, and sewage pipes.

In unheated buildings where the floors are usually laid on the ground, a pad of large pieces of gravel is built only for silty and ice-filled grounds covering a rock; on such grounds the principal communications are laid in a through or semi-through reinforced concrete channel, while the auxiliary communications are attached to the walls, as high as possible from the floor. As an example is the construction of the intershop heated sanitation compart-

ment (toilets, etc) in the unheated building of the shop. The floor of the sanitation compartment is raised by 0.5 meters above the floor of the cold building. This makes it possible to reduce the effect of the heat from the place on the base of the shop's floors and to attach the sewage pipes to the building's walls above the floors of the shop (Fig. 24).

Fig. 22. Ventilation room of nickel electrolyting shop
1) in plan; 2) section along 1-1; 3) section along 2-2; 4) up to one meter sagging; 5) foundation; 6) frozen ground; a) prior to construction (ventilation rooms and units on foundations erected on frozen grounds); b) after construction (ventilation rooms and units installed on reinforced concrete covers).

Fig. 23. Plant for reinforced concrete products. Overhead floors.

Fig. 24. Sanitary compartment inside the shop
a) sectional view along 1-1; b) plan; 1) reinforced concrete cover; 2) beam; 3) tunnels for pipes; 4) sewage pipe (attached to the wall; 5) rock; 6) floor of sanitation compartment; 7) floor of the shop.

The construction of a reinforced concrete passage for the principal communications requires large expenditures. In certain cases the warm-water and electrical communications should be arranged along the walls of the building or suspended to the ceilings and areas between the stories and the sewage pipes should be laid under the ground on supporting beams resting on the foundation brackets. It is recommended to hold the sewage pools also the cantilevers of the building's foundation and, in certain cases, on permanently frozen grounds by installing a pad of clay and concrete. The openings in the walls of the pools for the sewage pipes should be made large and closed by thin iron sheets or boards to enable the pool to deform freely without affecting the sewage system (Fig. 25).

Fig. 25. Sewage pipe installed on cantilevers
1) for inspection; 2) clay-concrete bottom of pool; 3) rock; 4) reinforced concrete cantilever; 5) sewage pipe, 150-300 mm in diameter; 6) supporting bar; 7) reinforced concrete beam.

For building nondeforming floors on a layer of medium thickness (up to 2-3 meters) of permanently-frozen grounds covering a rock, it is advisable to replace such grounds with thos which are made up of large pieces which can eliminate sagging when thawed. In this manner are built the floors in certain buildings of Noril'sk metallurgical and ore-concentration plants. In this case, The warm-water pipes and the cable networks can be laid on a layer of of grounds replacing those which covered the rock.

In building the first and second objects of the Noril'sk TETs, the floors were laid on replaced grounds. In building the third and fourth objects, the layer was exceeded by 3-4 meters and the floors were laid along a reinforced concrete span resting on foundations erected on the rock under the layer.

3. Buildings erected on thawing grounds

There is no difference between beds of ordinary grounds and those that are subjected to thawing and, therefore, the design used for erecting Noril'sk buildings on thawing beds were the same as used in the central belt of the country. It should be mentioned, however, that deformation was observed in certain buildings which made the operations difficult and made it necessary to repair and restore the buildings. As an example is the deformation of the auxiliary buildings of the coke and chemical plant. Due to the limited area occupied by the grounds with thawing beds, certain auxiliary buildings had to be located at borderline of the thawing grounds.

It should be noted that it is very difficult to determine the natural boundary between the beds of the thawing and permenently-frozen grounds. Also, the place where thse two types of soil join each other is usually characterized by the thawing grounds containing inclusions of frozen grounds, and vice versa, thawing inclusions in permanently-frozen soil. The transition from thawing to permanently-frozen grounds is formed over a distance of several meters of mixed (thawing and frozen) grounds. The exploitation of a structure may change the boundary of the thawing beds. The latter does not make it possible to determine the boundary line between the thawing and permanently-frozen beds with a precision required for arranging a joint for sagging.

Exploitation of the plant, especially of the warm-water communications, affected the contours of the grounds with thawing beds. The thawing of the grounds along the communications extended to the beds of the mentioned buildings and resulted in sagging foundations and deformed buildings. Damaged engineering communications caused the permanently-frozen grounds to thaw at the zone where they join the thawing grounds. The deformation of the communications took place mostly at the boundaries where the thawing grounds join the permanently-frozen ones.

The main buildings of the plant which were erected on thawing grounds mostly on belt-type foundations, whose walls and ceilings are of the conventional design, are in operation for many years and do not show signs of substantional deformations.

The specific feature of grounds with thawing beds are the tiny islands of permanently-frozen grounds found occasionally in the midst of the thawing grounds, which are difficult to find during engineeri ng-geological explorations. In Noril'sk, in the district of the October street, there is a large

section containing grounds with thawing beds on which are located several multi-story stone buildings, including an hotel, room for sports, etc.

The Buildings were constructed with heated basements on belt-type of foundations, i. e., their design did not differ at all from that of the buildings erected in the central belt of the country. No substantial deformations have been found during the period of exploitation. However, certain buildings located on the same section did experience saggings caused by the thawing of the tiny islands of permanently-frozen grounds.

In the public home sagging affected a corner which sagged irregularly by about 10 centimeters. The crack was repaired and further saggings have stopped. The deformation had for its cause the presence in the midst of the thawing grounds of sheets of ice-filled permanently-frozen grounds. This layer had thawed during the exploitation of the building and ground becoming more dense caused the corner to sag.

In the 4-story school building built in 1957 and located in the same district, through cracks were formed in 1959 which pointed to the sagging of the southeastern corner of the building. Upon uncovering the ground it was found that the bed on a section extending about 10 meters had sagged considerably. A space of 50-60 centimeters in height was formed between the bottom of the foundation and the bed. Of interest is the fact that the foundations did not sag simultaneously with the bed, because the walls and the concrete of the supporting walls were laid during the summer and had sufficient strength to support the weight of part of the building.

The collapse of the building was prevented by filling the empty space under the bottom of the foundations with concrete under pressure and heated electrically. The volume of the empty space under the foundation exceeded 10 cubic meters. The cause of the building's deformation was the presence in midst of the thawing grounds of a tiny island made up of ice-filled permanently frozen grounds.

Later, in designing buildings to be erected on thawing grounds, the following solutions were adhered to:

a) location of buildings on grounds consisting of partly thawing and permanently-frozen soils was avoided even when provided with sag-proof joints, if the thawing of the permanently-frozen grounds could cause a large sagging;

b) consideration was given to a certain possible change in the thawing contour caused by the subsequent exploitation of the structures; in erecting buildings on grounds remaining in a permanently-frozen state and adjoining a zone to be filled with buildings on thawing beds, steps were taken to protect the permanently-frozen grounds from the thermal effect (for example, from the warm water thrown on the surface as waste, warm-water communications, etc.) of the buildings and communications located in an area with thawing beds.

4. Buildings erected on preliminarily thawed beds

Preliminary thawhing of permanently-frozen grounds is mostly used on experimental sections. In Noril'sk, the thawing of permanently-frozen grounds was performed in large volumes to help their development during the digging of foundation pits, trenches, and for a vertical layout. In building the electrolytic shop, for example, a territory of about 5,000 sq. meters was warmed up at

the same time to a depth of 5-6 meters. The heating was mostly done either electrically or by steam.

The fine-grained, ice-filled soil were converted upon thawing into silt and occasionally into pulp (when thawed by electric heating) and were bailed out from the pits with the aid of pails or buckets. The supporting capacity became either insignificant or equal to zero. On such a preliminarily thawed section, even if dried to increase the supporting capacity of the ground on which to erect a building, the smallest degree of thawing caused by the exploitation of the building will deprive the bed of its supporting capacity and will deform the building.

Evidently, only grounds consisting of sand and gravel (large-skeleton type) are fit for preliminary thawing. In such a case it is still necessary to take into account that, in case of considerable saturation with ice, the thawing may not be simultaneously accompanied with an increase in the density of the beds and, later, the pressure of the building may cause the bed to sag extensively.

In Noril'sk, there was no previous experience with buildings specially designed by the method of preliminary thawing of permafrost grounds. Several buildings have been designed and erected on such grounds. For example, the oil-recovery shop of the Noril'sk petroleum base was designed in accordance with the method of retaining the permafrost state of the grounds. The presence of a temporary oil-recovery shop at the petroleum base made it possible to delay for several years the building of a permanent shop. In starting the digging of the foundation pits for a permanent building it was found that the ground had thawed to a depth of 10-15 meters due to the effect of the heat dissipated by the adjoining temporary building and by the outdoor hot-water pipes. The restoration of the permafrost state of the grounds required a prolonged period of time and major work for rebuilding the hot-water communications, Because it was necessary to shorten the construction time, the design was changed and the building was erected on preliminarily thawed grounds. However, the uncertainty of obtaining of completely thawed and compressed grounds over the entire area of the building and the lack of experience in designing and exploitation of buildings erected on preliminarily thawed grounds forced the designers to proceed with caution. As a result, the design aimed to make the building durable and to provide normal exploitation conditions with the ground sagging irregularly to a depth of up to 25-50 centimeters (Fig. 26).

The basic solutions provided by the design were based on foundations installed below the affected layer composed of swollen grounds to a minimum depth of 3 meters. In view of the insignificant pressure exerted by a one-story building, use was made of columnar foundations with monolithic beams, which together with the wall should provide a longitudinal rigidity for the building on the section between the sagging joints.

To prevent possible horizontal displacements of foundations and beams, the foundations are connected to the beams by reinforcing fixtures, while the beams are connected with the continuous reinforced concrete plate of the floor located on a fill of rock pieces of 1-1.2 meters in depth. The need of the reinforced concrete plate and of waterproofing is due to the necessity of reducing the irregular sagging of the floor, because during the exploitation the constant washing of the floors with cold water may result on water streams. The connection of the floor plates to the beams makes it possible to assure

an horizontal tie for different saggings of the foundations and beams; it will be retained even when cracks are formed in the plate at the place when it is joined to the beam, because the reinforcing fixtures of the plate enter into the beam. The monolithic reinforced concrete crosspieces above the windows serve simultaneously as a belt of reinforced concrete which increases the rigidity of the walls on the sections between the sagging joints. The top of the walls is jointed with the ceiling which limits the possibility of their deviation from the vertical axis.

Fig. 26. The oil-recovery shop
a) original version; b) version used for construction.

The short period of exploitation of the building is insufficient for disclosing the weak places and to offer any recommendations for their elimination, the more so, because the solutions contained in the design are to a large extent forced ones due to the previously constructed part of the foundations, the technology and the overall dimensions of the building.

The defect of such a solution is the low spatial rigidity of the building, which was later taken into account in designing building of similar type, the dissolving unit, for example.

The dissolving unit for making use of the ashes present at the TETs for construction purposes is located at a place used for pipes carrying the ash-removing water. Technologically, the pulp from the ash-removing water passes to the concentrating department of the dissolving unit. Then, the water which was previously wasted, is returned back to the TETs, while the concentrated ash mixture is used as a raw material by enterprises of the building materials industry. This made it necessary to locate the building on an area where, due to the effect of the neighboring structures, the bulk of the permafrost grounds becomes thawed to a considerable extent. According to an engineering-geological conclusion, the sagging irregularity may reach 50 cm.

Fig. 27. Dissolving unit for ashes from TETs
a) lateral section; b) top view of supporting plate

The building was designed to allow for plastic deformation of bed and by taking into account the possibility of formation of zones of zero-reactions. The area to be built up was filled with pieces of rock to a height of 1.1.5 meters (Fig. 27). The fill was covered with a corrugated plate of reinforced concrete, in form of a plate on two supports to take care of possible sagging of the bed under the middle section, and in form of a cantilever to take care of the irregular sagging of one of the outside section of the bed. The plate has a rigid spatial frame reaching the marks of the covers on which is installed the heavy technological equipment. Above that are located the rooms enclosed by light-weight walls made of cement-fibrolite plates.

This design assured stability for the building when deviating from the vertical axis due to the irregular sagging of the extreme end of the section. In case sagging of the building, provisions are made to be able to level individual units to set them in horizontal position and, for this purpose, the anchor bolts are made longer and metal wedges are set under the supporting frames. This provides normal exploitation conditions for both the building and the equipment.

5. Buildings erected on permafrost grounds by taking into account their subsequent thawing

The sagging of buildings due to compressed ground is an ordinary phenomenom in all regions of the country and such saggings usually do not exceed several centimeters. Entirely different is the nature of the phenomena when the thawing of ice-filled permafrost grounds makes them sag by tens of centimeters. Here, the sagging irregularity depends not on the pressure difference on the ground, but on the depth of thawed beds under the foundation.

The designing of buildings in accordance with the method of subsequent thawing of the grounds began as early as in 1939-1940. These included the complex of shops of the mechanical plant, the central motor-vehicle base, etc. The technical solutions provided by the designs of these buildings and the individual defects disclosed by their exploitation are described below.

According to the data of the engineering-geological explorations of the construction sites of the mechanical plant it was assumed, that, irrespective of the pressures on the ground, the thawing of the beds will make the foundations sag by 30 centimeters and the irregularity of tha saggins will reach up to 15 centimeters. The plant buildings had to be filled with heavy technological equipment and powerful bridge cranes. This mechanical plant is already built and its buildings are normally exploited for a duration of 15-18 years. This was achieved by designing a carcass that assured the stability of the building despite the considerable shifting of individual units.

The precast reinforced concrete columns were rigidly embedded in reinforced concrete footplates. The precast reinforced concrete beams rested on footplates or on the brackets of the columns. The precast reinforced concrete or metal plates under the cranes rested on the brackets of the columns.

The anchor bolts on brackets for the metal plates under the cranes had an elongated protruding part which, in case of sagging columns, made it possible to raise the plates with the aid of metal or wooden wedges.

The metal girders of the covers have hinged supports with oval openings in the supporting plate to allow for a certain displacement of the top of the column in case of sagging.

In designing the frame structure to take care of the loads due to the wind and the cranes, it was assumed that the girders serve as an hinged

connection (despite the possible mobility of the supports due to the oval gaps in the supporting plate), because the frictional force by the bearing reaction of the girders is by far larger than the obtained in this case the calculated forces H_1 and H_2 (Fig. 28). The H_1 and H_2 forces were taken into account in designing the girders because, in case of irregular sagging of foundations, the girders restrict the top of the columns from deviating from the vertical axis and allow at the same time their free vertical sagging.

Fig. 28. Design of carcass of the shop for metal structures
— steady and temporary loads of overhead structure; P_v and P_h) the load due to the crane; q_v and q_o) the load due to the wind.

The design of the equipment foundations took into account the possibility of an irregular sagging; this made it necessary to calculate their deflection when serving as beams supported in two places (when the sagging affects the middle part of the bed) and as cantilever beams (when the sagging of the bed is at the edge of the foundations). For this, it was necessary in many cases to reinforce both the upper and lower zones of the foundations (Fig. 29).

The pipes for heating, water, sewage, and electrical cables were installed as much as possible higher than the level of the floor and were attached on flexible hangers to the carcass of the building.

Fig. 29. Design of foundation for large equipment
a) thawing of the middle section; b) thawing of the right section; c) thawing of the left section.

The crane tracks were secured to the beam in a manner that made it possible to easily adjust them vertically and horizontally (Figs. 30 and 31). The design increased the dimensions from the head of the crane track to the lower belt of the girders and from the axis of the track to the facet of the column, on the assumption that there may be irregular saggings and deflection of the top of the columns. The foundation anchor bolts (for the equipment) were made 10-15 centimeters longer. The mortar poured under the machine tools reached the bottom of the frame, which made it possible to level them easily in case of irregular sagging of foundations. The dimensions of the doors and above the equipment took care of the magnitude of the assumed irregular sag.

Fig. 30. Securing metal beams under the crane to the reinforced concrete columns. 1) elongated by welding; 2) wooden pad.

Fig. 31. Securing the crane tracks to reinforced concrete beams. 1) wooden wedge through 60 cm; 2) welded.

The experience in exploiting the buildings of the plant and of other buildings disclosed also the errors made in designing certain units and structures because the special features of erecting buildings under the given conditions were not taken into account; this made it necessary to rebuild later certain units and to reinforce the structures.

The building carcasses built in accordance with the method of subsequent thawing become more frequently destroyed due to using an incorrect m ethod of designing. The rigid frame-type of reinforced concrete carcasses, which are economical under ordinary conditions, are entirely unfit for buildings built in accordance with this method.

For example, one of the buildings of a small metallurgical plant (does not exist atthe present time) built in 1939-1940, where the supporting carcass was built in form of a single-span, rigid, frame of reinforced concrete was destroyed. The cause of the destruction was a local thawing of the bed of the grounds which was overlooked during the use of the building and which caused an irregular sagging of the foundations by a magnitude much larger than the calculated sagging. During the sagging, certain foundations not only shifted vertically, but also turned at their foot (Fig. 31a); this was caused by the irregularity of the sagging bed over the area of the foot of the foundation. It tore off the foot of the foundation from the column and formed cracks on the outer side in the upper part of the column and in the inner side where the column and the foot were joined together.

In another carcass frame, the one located alongside, the saggings of the foundation foot occurred along the vertical line and the cracks appeared at the inner side of the columns and cross bar at the connecting joint (Fig. 32b).

Fig. 32. Damaged reinforced concrete carcass frame of the building of the Noril'sk metallurgical plant
a) deformation due to irregular thawing of the foundation foot; b) deformation due to uniform thawing of the foundation foot.

Fig. 33. Types of reinforced concrete carcasses
a) monolithic (rigid); b) assembled (pliable).

Of course, the design of rigid reinforced concrete frames could take into account larger saggings and possible rotation of the foundation foot, but this would increase considerably the cost of construction. Stability for the reinforced concrete carcasses can be obtained by designing them in the form of separately standing columns held rigidly in the foundation shoes with hinge-connected cross bars (girders) along the top (Fig. 33).

The defect of pliable carcasses is that, in case of a single-span, lateral arrangement, an irregular sagging of the bed in the plane of the foundation bottom may result simultaneously in deflection of the columns from the vertical line and in destruction of the carcass when the foundation-bottom makes a large turn. This, however, can be avoided by constructing horizontal "wind connections" along the belt of the girders, or by constructing reinforced concrete roofs connecting the upper parts of the columns. This may reduce

the possibility of deflections by individual columns without reducing the possibility of vertical sagging.

For separately-standing columns with unconnected tops, the lateral deflection from the vertical axis can be reduced by developing to a maximum the foundations in direction of the effective section of the column. The deflection of the columns from a vertical axis in longitudinal direction can be avoided by constructing braces in the plane of the building's walls (reinforced concrete beams, through belts of crosspieces, braces along the top of the wall, and beams under the crane).

In designing carcasses it is necessary to take into accont the possibility of additional forces in the cross bars (girders) which appear during irregular saggings of the bed of the grounds. To a larger extent, this concerns buildings with metal carcasses. In this case, designing of rigid carcasses by taking into account the possibility of sagging requires structures whose weight is so much larger that their application becomes unworthwhile. Attemps to reduce the irregularity of the saggings by using a rigid carcass in the plane of the longitudinal walls (Fig. 34) made it necessary in many cases to reinforce the carcasses in order to avoid the collapse of the building.

Fig. 34. Types of metal carcasses

a) rigid wall carcass (cross bars and columns rigidly connected); b) pliable carcass (with hinge-connection of cross bars with the columns).

For buildings with metal carcasses erected on beds subject to large irregular saggings due to thawing, it is necessary to use carcasses of the pliable type with the girders and braces hinge-connected to the columns. In such a case, it is sufficient to place one rigid insert in the section between the temperature joints which will assure stability of the walls in a longitudinal direction. For this, it is absolutely necessary to be sure that the foundation of this insert is rigid, because an irregular sagging of the supports without a simultaneous turn of planes of the supports may destroy the rigid insert and tha carcass of the building.

If the sagging of the supports (axes 3, 4, 5, etc. in Fig. 34) is large and irregular, this method will assure the stability of the carcass in a longitudinal direction and the horizontal ties will help to a considerable extent to retain the parallel position of the columns after their sagging. For a foundation sagging of the same irregularity, an increased distance between the rows 1 and 2 of the insert will reduce the deflection of the building's columns from the vertical axis.

With a multi-span pattern it is advisable to assure the stability of the metal carcass of the building by having a rigid span and, for large spans, by constructing a single row of columns with foundations developed in the direction of the lateral axes and hinge-connected columns and cross bars. In designing carcassed buildings, the use of these recommendations will assure the stability of the carcasses and a minimum deflection from the vertical axis; it will retain the external appearance and the exploitation conditions for a building subjected to large irregular saggings.

Formation of cracks in the walls

The large irregularity of foundation saggings (in Noril'sk it is more than 10-15 cm between two adjacent columns) is responsible for cracks forming in brick walls despite the fact that the design provided frequent separating slits with joints for sagging. Such cracks do not affect sifnificantly the stability of the buildings, but they are extremely undesirable for the conditions of the northern regions. Foundation sagging that continues for many years is accompanied with a steady formation of cracks requiring frequent repairs for the building (Fig. 35). Later, in designing brick buildings, the walls were separated by sagging joints to take care of the expected large irregular sagging of the foundations; this was done for each of the spans. It assured their safety and had eliminated the formation of cracks (Fig. 36).

Fig. 35. Formation of cracks in walls of buildings

The use of large wall panels is to be especially recommended for the walls of carcassed buildings erected on beds subjected to large sagging. In

this case it is possible to arrange the joints in a manner that will not affect the external appearance of the building even with greatly sagged columns.

Fig. 36. Separating slits in the wall of the charge-mixing yard

Irregular thawing of the ground bed

In designing and operating the shops inadequate attention was paid to the possibility of moderating the irregularity of the saggings by creating homogeneous temperature-moisture conditions in the shops. For example, dumping of hot water was permitted in the forging-heat treatment shop which resulted in intensive local thawing, sagging of foundations, and formation of cracks in the wall. Under the front wall of the shop for metal structures the ground was used for admitting the heating system which resulted in an irregular thawing of the bed. The deformation turned out to be se large that a part of the wall had to be rebuild (Fig. 37).

Fig. 37. Defotmation of front wall of shop for metal structures

Intensive local thawing was also observed in other buildings of Noril'sk built in accordance with this method. The thawed depth reached in a short time the ultimate value used for determining the maximum extent of the thawing and the sagging irregularity reached up to 80% of the absolute. In a predominant majority of cases the causes responsible for the irregular sagging of the bed were not the defects of the design, but the negligence during the exploitation. Still, in individual cases it is necessary to take into account the possibility

of similar phenomena in this type of building, and, if it does not increase appreciably the construction cost, the design should make provisions for possible higher irregular saggings.

In Noril'sk, the capital expenditures for repairs and restoration were by far higher than the possibly higher cost of buildings designed by taking into account larger irregular saggings.

Violation of norms for dimensions above the equipment

The irregular sagging of columns in buildings in many cases exceeded the assumed irregularity and reached 20-25 cm when the assumed irregularity of vertical saggings was expected to equal 15 centimeters (Fig. 38). At the level of the beams under the crane, the columns were deflected from the vertical axis by 5-10 centimeters in a direction perpendicular to the longitudinal axis of the beams. In certain places where the anchor joining of the beams under the crane was poorly executed, the deflection of the columns took place along the axis of the crane beams which caused the butt-joint to be displaced beyond the axis of the support. While not affecting the stability of the building, these deformations made the exploitation difficult and made it necessary to take several steps to assure normal shop operations. However, a number of factors appeared which made it more difficult to execute these steps.

Fig. 38. Sagging of foundations of boiler-rolling shop

1) sagging of foundations of reinfirced concrete carcass, in mm;
2) along the axis c and D.

1. The straightening of the crane tracks in plan was restricted by the distance from the axis of the crane track to the facet of the column. The deflection of the column from the vertical axis at the level of the crane track was 30-40% of the actual irregular vertical saggings and in many cases was larger than that which was taken into account by the design and which is equal to the dimensions specified by the norms plus 30-50 centimeters. This made it necessary to cut off the concrete of the upper part of certain columns (Fig. 39). Also, the deflection of certain columns was so large that cutting off the concrete to a point which would not impair the strength of the column did not yield the required dimensions and it was necessary to cut off the entire upper part

of reinforced concrete and replace it with a smaller metal structure.

Fig. 39. Concrete cut off from deformed columns to obtain required dimensions for the crane

2. The vertical straightening of the track on certain sections to 25 centimeters (because the irregularity of the vertical saggings exceeded those of the design) made the distance from the head of the rail to the bottom of the girder inadequate. In the lateral spans of the shop the vertical dimensions for the crane were increased by raising the girder and adding 15-20 centimeters to the supports. In the middle span, due to the difficulty in raising the monolithic reinforced concrete plate, it was more expedient to rebuild the girder (under load)by introducing new structural components and, in particular, a new lower belt (Fig. 40) and the old lower belt was removed thereafter.

Fig. 40. Raising the lower belt of girders in the shop for metal structures, due to inadequate crane dimensions

—— retained girder rods; ━━ new girder components;

--- cut off part of girder.

In buildings with supports subjected to large irregular sagging by irregular thawing of the ground bed, the distance from the axix of the crane track to the protruding facet of the columns (wall) should not be less than the sum of the values taken from the table dimensions for cranes and the maximum assumed deflection of the columns from the vertical axis at the level of the beam under the crane. With an accuracy adequate for designing, the extent of the deflection (as a maximum) can be taken as 1 centimeter per 1 meter of the distance from the foot of the foundation of the columns to the mark of the head of the crane-track for each 10 centimeters of the assumed irregularity of the building's sagging. These recommendations are based on the investigation of maximum deflections of columns from the vertical axis (with thies present at the top in form of girder and covering plates) in the buildings of the Noril'sk mecanical repair plant. The maximum angle of deflection of the columns from the vertical axis did not exceed 45' for an irregularity of saggings reaching up to 25 centimeters.

The obtained deflections of the columns and the respective increase in eccentricity of vertical loads (Fig. 41) should be taken into account by the design of the structures, although these increases are usually not essential.

Fig. 41. Deflection pattern of columns due to irregular sagging of beds

The vertical crane dimensions (from the mark of the rail head to the bottom of the girder) are obtained by using for the design the dimension recommended by the table of cranopdimensions plus the maximum-possible extent of irregular sagging. For certain columns this value was actually equal to 0.8 of the absolute sagging. The selection of dimensions for other type of equipment (lathes, electric control panels, etc.) should be approached analitically.

Inadequate survey of grounds for foundations

The Noril'sk buildings erected in accordance with the method described above, in particular those which avoided the defects present in the earlier design of the carcasses of the mechanical-repair plant, have shown good results in both the stability and strength of supporting structures and in satisfying the technological requirements for their exploitation.

However, the local seats of the foundation grounds together with exploitation defects allowed to take place (creation of local seats of intensive thawing) which were not taken into account by the design were the cause of the extensive deformations in the building of the body-repair shop of the auto-repair base. Cracks appeared in the outer wall above the foundations. This does not affect the stability, but impairs the external appearance of the building.

The inadequate engineering-geological survey of the site intended for the construction of a 12-car garage resulted in its destruction after two years of operation (Fig. 42).

Fig. 42. Destruction of 12-car garage

The deformations and destruction of the body-repair shop, of the 12-car garage, and of other buildings could have been avoided by designs based on the the data obtained by a study of the engineering-geological conditions of the building sites. The volume of engineering-geological surveys preceding the working design must be considerably larger than the survey for a working design of building sites outside the zone of permafrost grounds.

6. Buildings erected on grounds retaining their permafrost state

Deformations of operating buildings

The limited extent of rock outcroppings on the surface and of areas with thawing or large-skeleton nonsagging grounds makes it frequently necessary to build only by the method of retaining the permafrost state for the foundation grounds of the structures. Serving as an example are the cities

of Dudinka, Igarka, Yakutsk, and other towns of the Extreme North, where the type of the frozen foundation-grounds, as a rule, eliminates all other methods of erecting buildings [see Note].

([Note]: ice-filled, fine-grained sandy soils, dusty and silty soils, or soils containing clay with separate sheets of ice are the predominant type).

The experience of many years in designing and building industrial and civil buildings by using the method of retaining the permafrost state of the foundation grounds makes it possible to assure their durability and to satisfy the operating and technological specifications required for the structures. Nevertheless, a number of buildings constructed in Noril'sk, Vorkuta, Igarka, and other towns of the Extreme North experienced considerable deformations and were even destroyed. Errors were allowed to take place in the designs of certain buildings under construction, for example, when expanding the Yakutsk electric station.

In the existing part of the electrostation building, the ground surface of the basement has a multilayer insulation (a layer of asphalt, wooden sticks, clay, etc.) which is expensive and extremely difficult to arrange. Yet, the annual average temperature in the basement is below zero and, therefore, the foundation grounds are not insulated against heat, but on the contrary, against the cold which helps to keep the grounds in permafrost state. The height of the ventilated basement is very small and its inspection is not possible. Considerable quantities of hot water penetrate through the ceiling into the grounds, the result of which is a thawed foundation ground and the sagging of the building. The same defects are also repeated for the expansion of the electric station. Similar unreasonable designs were used also in other regions of the Extreme North.

The method of erecting building on grounds by retaining their permafrost state is known for a long time. In Yakutsk there are buildings erected several centuries ago. Similar examples can be cited from the history of Dudinka and others. The designs of these buildings provided for the absence of heat-transfer to the foundation grounds, which was effected by building warm floors and ventilated cold basements.

Such a solution without taking into account the operating conditions does not always assure the durability of the structures. The buildings equipped with ventilated basements which were designed and built during the first few years of mastering the cities of Noril'sk and Dudinka experienced in many cases serious deformations and even destructions. The small metallurgical plant was built in Noril'sk in 1940. Deformations of the buildings of the electrolytic and cleaning departments, where the technological process was accompanied with large quantities of water and solutions falling on the floor, began to take place several months after the start of operations. During the second year of operations the deformations of the buildings assumed a dangerous proportion (Fig. 43). Despite the frequent repairs for restoration, the building was demolished after three years of operation.

An examination of the deformations of the electrolytic department of the small metallurgical plant, also of several lesser deformations of the Noril'sk and Dudinka temporary electric stations (both built in 1939-1940) had disclosed the basic cause, namely, inadequate heat-and-water insulation of the roof above the basement. This is indicated by ice (icicles) formed in the

basement (Fig. 44). The destruction could have been prevented by timely inspection and correction of the penetration places in the ceiling of the basement, but its low height made an inspection impossible. In buildings erected on grounds kept in a permafrost state, the height of a ventilated basement must be designed with a view of possibility of its inspection. If no engineering communications are passing through the basement which require a certain height, the basement should have a height of not less than 70-80 cm. For buildings in which moisture is required for the technological process, the height of the basement should be increased to not less than 1.2 meters for easy periodical inspections. The ceiling above the basement should have a heat-insulation satisfying the norms for temperature drops inside the buildings. The buildings where falling of water on the floors is possible must be equipped with extra-good insulation against water (multilayer insulation of roofing materials on mastic, metal sheets with well welded seams, etc.).

Fig. 43. Deformation of electrolytic shop of small metallurgical plant

In Noril'sk, in 1938-1940 were built major one- and three-story buildings with ventilated basements of 25-50 cm in height and with warm ceilings above them. Originally, heat came from the furnaces and there was no water supply and no sewage system. For several years of operation, no signs of building deformation have been observed. Substantial deformations resulting in destroyed structures (Fig. 45) appeared after the buildings were equipped with a central heating system from an outside supply of heat, and with a water-supply and sewage systems.

Most typical is the deformation of the three-story stone house at the October street in Noril'sk. No signs of deformation were observed for a period of 20 years (the house was built in 1939). In 1959, one of the sections of the house became so seriously deformed that the residents had to move out before steps were taken for restoration. The cause of deformation was due to equipping the house in 1958 with a water-supply and sewage systems (central heating was installed at the beginning of the exploitation).

Fig. 44. Formation of icicles on the basement ceiling

Fig. 45. Destruction of public residential house

The sewage system was installed in an inaccessible for inspection ventilated basement of 50-60 cm in height and, instead of suspending to the ceiling, certain pipe sections were installed in the ground. The leaks formed

at the joints resulted in thawed grounds, sagging and destroyed joints, after which, the sewage water reaching the foundation grounds caused an intensive thawing of the grounds and a sagging of part of the house. The cause of the listed deformations was the incorrectly installed heat and water-supply systems in the building (see p.69 for recommendations for installation of engineering communications).

Fig. 45. Destroyed building of a public home

In 1945 was destroyed a corner of a three-story residential house (Fig. 46). The destruction was also caused by the thawing of the permafrost foundation grounds due to the action of the temporary heat-supply line installed in an underground uninspected housing at a distance of 10 meters from the corner of the house. The removal of the heat supply made it possible to restore the permafrost state of the grounds and to repair the building, which is still in good order at the present time.

Similar deformations of earlier-built building, which were later improved with engineering utilities, took place also in other regions of the extreme north. The installation of central heating caused serious deformations in many buildings of Igarks and Dudinka. The same cause is responsible for the deformations of the oldest buildings in the city of Yakutsk, among which was a building built 400 years ago. The engineering utilities, including also a cable network, xxxx installed underground either in conduit inaccessible for inspection or without conduit caused the destruction of certain structures built on the surface (connecting and inclined transporting platform of the substation) above the mine No 27 and of several residential houses in the city of Vorkuta.

The cause of the listed deformations was the non-observance by the designed engineering utilities (passing near the structures) of the conditions

that would prevent the heat from the utilities from affecting the soil under the structures; also, because the building designs did not take into account the conditions that can assure the durability of the buildings using such utilities.

Fig. 46. Destroyed corner of 3-story residential house in the city of Noril'sk

In Noril'sk, the durability of buildings served by engineering utilities is assured by installing the latter under conditions excluding their heat action on the foundation grounds (by installing in above-ground or ventilated through conduits), or by protecting the grounds from the heat of the near-located utilities and structures (see below).

Protecting the grounds from the heat of near-located buildings

The sources of possible liberation of heat located near objects under construction must be carefully studied irrespective of their capacity, since the temperature conditions of the grounds can be affected even by sources of low capacity. An especially thorough study must be made of the effect of adjacent structures on the grounds of the buildings and, if necessary, to take steps that can prevent the grounds from thawing. Especially menacing are the heat and water supply systems and the enterprises from which large quantities of warm water may penetrate into the ground. An example can be cited from the practice in designing and exploiting the building for storing the coal of the Noril'sk TETs (central electric station).

Fig. 47. Drainage protecting the coal storehouse of TETs
a) view along 1-1; b) top view; 1) pipeline; 2) filled with soil; 3) tightly tamped clay; 4) dumping ground; 5) filled with stones; 6) drain.

The unheated building for storing the coal was designed in 1938 by using the method of retaining the permafrost state of the foundation grounds. The design took into consideration the TETs circulating water supply with the pipes passing over a distance of about 125 meters along the natural slope of the grounds from which the penetration of warm water into the foundation of the storehouse building was possible (Fig. 47). Also, the city's central heating system had the pipes laid on the surface over a distance of about 30 meters; a leaking pipe could also cause a local thawing.

The foundation ground of the storehouse was protected from the harmful action of the underground flow of water from the upland side of the building by designing a drainage system and a waterproof layer of tamped clay. This, however, did not protect the grounds from thawing. The empty spaces between the stones of the fill became filled with ice. The accumulated water had penetrated below the natural surface of the grounds and formed there individual underground streams flowing out as underground spouts along the slope below the building. Serious deformations and destroyed structures appeared in the building.

In enlarging the storehouse, the drainage was built in form of an open trench reinforced by wooden walls whose bottom was 1-1.5 meters below the natural surface. Provisions were made for the possibility of inspection and cleaning the trench. The 15-year exploitation confirmed the correctness of the adopted design. No cleaning was necessary for the drains and no signs of ground thawing were found in the enlarged part of the storehouse.

In designing the protection of the grounds against the effect of adjacent structures it is necessary to take into account that the extent of the thawing

at nearby buildings usually spreads little beyond their contours and does not threaten the durability of a building erected at a certain small distance, provided that the possibility of formation of underground and above-ground water flows is excluded during their exploitation. However, the presence of water and heat pipelines, particularly when leakes of water into the ground is possible, is extremely dangerous even when the space between buildings is large. In such a case, the best protection for the grounds is by building drains of the trench type that can be inspected and cleaned during their exploitation.

Occasionally, instead of an expensive draining system it is more advisable to remove the source of heat liberation (underground warm-water pipes) from the section intended for building. In this case, however, it is necessary to take into consideration the time required to restore the permafrost state at this section.

Use of ventilated basement to retain the permafrost state of the grounds under industrial buildings

At the present time, the protection of foundation grounds against the heat liberated by the building itself is designed in a different manner in different regions of the Extreme North. Hence the different results obtained for the durability of the buildings obtained during their exploitation. For example, according to the data of the group of experts created in 1959 by the Gosstroy USSR, a large number structures built above the mines in Vorkuta became deformed to a degree that made their exploitation difficult. Of 400 investigated buildings 320 were deformed and required repairs for restoration.

Deformations in a large number of buildings occurred in the settlement of Myandzha (district of Kolyma), in Igarka, Cape Shmidt, and others. In Noril'sk, the majority of the major buildings were constructed by the method of keeping the foundation grounds in permafrost state. At this, certain of the buildings are based on solid masses of burried ice. The durability of these buildings was proven by many years of exploitation. Along with this, there are certain buildings, built mostly in 1940-1945 with designs different from those used at the present time, which became deformed. Examples of construction methods used for certain buildings and the reason why these methods can be recommended for later designs are given below.

The two-story brick house of the main building of the Yakutsk Leather Combine was erected on precast reinforced concrete foundations burried by 3.5 meters below the layout mark. A ventilated basement was built to protect the foundation grounds against the heat liberated by the quarters. The surface of the ground in the basement was covered by a heat-insulating layer. The height of the basement from the heat-insulating layer to the protruding structures is about 50 centimeters, the distance along the perimeter from the layout mark to the bottom of the beam structures is 20-30 centimeters. The ceiling over the basement has a complex water-and-heat insulation (Fig. 48). A sewage pipe and a settling tank were built in the ground at a distance of several meters from the wall.

This design has substantial defects. The installation of sewage pipes in frozen grounds near the building is undesirable, because as soon as the exploitation of the sewage system will begin, there will be thawing and sagging

around the sewage pipe and, later, the sagging will damage the entire sewage system. Warm water reaching the foundation will cause its ground to thaw and sag intensively; this may deform or damage the building. The low height of the basement makes it unfit for inspection; the latter would be particularly desirable for that section of the building where the technology of its shops requires constant washing of the floors and where the penetration of water through the basement's ceiling into the ground is possible.

Fig. 48. Ventilated basement of Yakutsk Leather Combine

The basement ceiling is made of: reinforced concrete plate, 150 mm; pergamyn over asphalt mastic; slag , 450 mm; slag concrete, 50 mm; cement tie rod, 20 mm; layer of ruberoid over each layer of pergamyn; asphalt, 25 mm; reinforced concrete plate, 40 mm; xylolith 13, with 1:4 composition; xylolith 12, with 1:2 composition. 1) heatproof layer.

The basement should have been made with 1.2 to 1.6 meters in height; the sewage and other pipes should not be laid on the ground, but should be hanging on the parts of the ceiling, high above the basement, or on the foundations. The sewage settling tank should not, as a rule, be built near the building. Before they enter the basement the sewage and other pipes should be laid above the ground and, if the layout forbids an above-ground installation, they should be laid in a ventilated channel open at both ends. In such a case, the building's foundation must be set deeper at the places where the pipes enter the basement and the thawing bowl formed under the channel should be taken into consideration. The insulation against heat of the basement's floor is also unnecessary in view of its annual average temperature of below zero. It increases the cost of construction and it (the insulation) impairs the conditions required to keep the grounds in permafrost state.

Fig. 49. Boiler room of Yakutsk Leather Combine, sectional view

Even in buildings where the technological process is not connected with water falling on the floor, the construction costs are also increased by the unreasonably used complex method of heat and waterproofing the ceiling above the basement. With a monolithic reinforced concrete plate covering the basement, it would have been sufficient (as proven by the experience with constructions in Noril'sk) to cover the plate with asphalt, or use one layer of roofing insulation without adhesives.

The Yakutsk building for the boiler room has a basement (Fig. 49) containing the same defects as in the production building of the leather combine.

Keeping gaspipes and ash-removal in heated quarters is unnecessary; it requires a larger space and increases unreasonably the cost of construction.

As a comparison can be cited the boiler room in Dudinka. Although equipped with boilers of larger capacity than those of Yakutsk, the Dudinka building occupies less space than that of Yakutsk. Instead of using ventilated space under the floor, the first floor is unheated and admits cold air during the winter. The ash-removal equipment and the pipes are located on the first floor (Fig. 50). The building is in use for many years and there are no signs of deformation or of thawed grounds. Whenever heating is required for certain parts of the first floor, space is provided under its floor, which can be ventilated and fit for inspection (this was done for the boiler rooms in Noril'sk and Dudinka).

The design used in Yakutsk cannot be recommended for boiler rooms. It requires larger volumes of space and higher construction costs, but it does not prevent the penetration of water and utilities into the space under the floor and, therefore does not prevent the possibility of thawed grounds and

deformation of the building. Instead of building special ventilated basements for boiler rooms and other industrial buildings, it is advisable wherever it is possible to provide the first (ground) floor with unheated auxiliary quarters and utilities that can assure the entrance of cold air.

Fig. 50. Ventilated space under the floor of auxiliary quarters of boiler room. 1)grate with shutters.

Construction of ventilated channels under the floors of industrial buildings and warehouses

The freezing of ground beds under foundations with cold air supplied through pipes or channels is widespread in the regions of the Extreme North. The cooling systems, however, are designed in a different manner in different regions. Certain cooling systems in use are described below, in order to enable the designers to select the most efficient version.

In Yakutsk, the garage building is provided with channels for freezing the ground beds during the winter season (Fig. 51). The bed is made heatproof by a clay enclosure over which is laid a layer of slag and concrete floors. The durability of the building depends in this case on the size and shape of the thawing bowl. When dry, the slag restricts the transfer of heat from the building to the soil of the bed; this notwithstanding, with air temperatures remaining steady above zero in the building, the thawing may reach a maximum depth of 10-15 meters in the final analysis.

The channels for freezing the beds were not designed successfully. During the construction period they may become filled with debris; during the winter even a light snowstorm or snowdrift will pack the channels with snow. To prevent the channels from being filled with snow is impossible in view of their small size. In the final analysis it is rather doubtful whether they can influence somehow the contour of the thawing bowl. In this case the zone

of thawing will spread under the foundation beds and may substantially deform the building. It should be added that warm water penetrating into the beds from the pipes, heating accessories, or from washed machines will expedite and increase the deformation of the building (in this case, the insulating layer of clay specified in the design will be rather ineffective).

Fig. 51. 25-car garage in Yakutsk, sectional view

Fig. 52. Sectional view of hangar built on swollen grounds. Combined protection of permafrost state by filled grounds and basements

More successful is the design which provides for freezing the ground beds over the entire area of the building. This method was adopted for the design of an hangar (Fig. 52) developed for the regions of the Extreme North.

The possibility of inspection and of cleaning the snow and dirt from the basement and from the cooling pipes assures to a considerable extent the reliability of the system and the permafrost state of the grounds. All that is necessary is to increase somewhat the height of the basement to make its exploitation more convenient.

In many cases the cooling unit is designed with forced circulation of the cold air to assure the permafrost state of the grounds. In Noril'sk, for example, freezing of the grounds beds included the building of the temporary electric station, the TETs storehouse for coal, etc. The same principle was used also in designing one of the mechanical assembling shops (Fig. 53). At a depth of 2 meters from the surface of the grounds are located the pipes through which cold air is pumped during the winter season to freeze the ground beds. This solution assures the durability of an industrial building when the technological process does not involve water falling on the floor. However, the large consumption of metallic or reinforced concrete pipes, higher requirements for exploitation of the cooling system, and difficulties connected with removing the snow and ice from the pipes do not favor, as yet, the wide use of this method.

Fig. 53. Sectional view of mechanical assembling shop
1) to the ventilator

The advantage of the system using channels for cooling the ground bed is that the load from the floor is not transmitted to the foundations of the building and that it makes it unnecessary to build heavy structures for the ceiling of the ventilated basements. For a comparison of the designs of buildings with cooled ground beds by means of ventilated channels, of interest are the buildings of the heated warehouse built in Noril'sk.

The one-story brick buildings are so constructed that the load on the foundations are transmitted only by the weight of the building's structures. Because the warehouses are located ina swampy territory, the design provides for using ventilated channels built immediately under the warm floor; the mark for the bottom of the channels is 50-70 centimeters higher than the layout mark. The channels can be easily inspected and cleaned of snow when necessary (Fig. 54). The area covered by the channels is equal to 80% of the area of the buildings floor, which provides the required freezing of the bed in winter. The channel walls are laid on a fill of large pieces of rocks.

Fig. 54. Warm warehouse in Noril'sk
a) sectional view; b) view along a-a.
1) air holes in lateral walls; 2) the lateral walls are made of 250 mm bricks on a fill of gravelous grounds.

The natural ventilation of the channels, their accessibility for inspection, the ratio between the areas of the channels and of the floor of heated building, and the simplicity of erecting the structures make it possible to recommend this design for warehouse and industrial buildings where the technological process does not involve the possibility of large quantities of water falling on the floor.

Construction of ventilated basement to preserve the permafrost state of the grounds under residential, cultural, and general-purpose buildings

The basic solution to preserve the frozen state of the grounds under residential, cultural, and general-purpose buildings is the construction of a ventilated basement. The purpose of the basement may differ, depending on how well the building is constructed, the permafrost characteristics of the beds, climatic conditions, and how substantial is the building.

In separately located buildings not equipped with central heating, water pipes, and sewage, the role played by the basement and the roof over it is to protect the building from cold and to prevent the heat from the building to reach the ground bed. A basement height of 30-50 cm can be used for such buildings. The air holes and the walls of the basement should be able to maintain in it an average annual air temperature below zero. In such a case, the

thawing of the grounds in the basement usually will not exceed the maximum height of seasonal thawing of the region under construction. This principle was used in building many wooden and brick houses in Yakutsk and several buildings in Noril'sk put to use in 1938-1942.

Ventilated basements of 30-50 cm in height are still built, even now, in Yakutsk, Igarka, Vorkuta, and other regions. The building of closed basements was discontinued since 1943 in Noril'sk and Dudinka, because they did not solve the problems connected with improving the buildings and the streets. The practice of designing and constructing multy-story buildings erected on fine-grained, ice-saturated grounds made it possible to develop the most efficient designs for ventilated basements.

Under the entire building extends a continuous ventilated basement built without intermediate walls and partitions. Its minimum height is 0.8-1 meter in places containing no utility pipes, and not less than 1.6-.18 meters in places where pipes are present. The pipes supplying heat and water and the electric cables proceed as much as possible directly from their entrance into the basement straight to the rooms located above its roof, or they are attached to the ceiling with the aid of hangers. The water (from damaged pipes) is prevented from penetrating into the ground by a reinforced concrete trough laid along the pipeline. The basement is designed with a slope to the trough. This makes it possible in case of damaged pipes to direct the water into the sewage (Fig. 55).

This design makes it possible to bring in all engineering networks into the building's basement from the street header which was built to preserve the frozen state of the ground and its bed. The street heasers, the entrances to the buildings, and the pipes in the basement are systematically inspected and, if necessary, repaired. As a result, due to this design for basements and pipelines, no cases of deformation of buildings were observed in Noril'sk during their 15-year period of exploitation.

Entirely different are solved the problems for pipelines and ventilated basements in Yakutsk. The basements are 30-40 cm high and 15-20 cm along the perimeter of the building where the wall beams are installed; this prevents any kind of inspection. The network of pipes for water, sewage, and heat supply are lead into the building above the layout mark into a layer of heat insulation for the ceiling above the basement.

This design cannot be recommended for the following reasons. Pipes entering the building at a place above the layout mark impair the well-ordered arrangement between the street blocks; the separation of the sewage pipes in ceiling is extremely faulty, considering the exploitation conditions. Also, the limited height of the heat-insulating layer makes it necessary to build several independent sewage entrances. The installation of sewage pipes under the ground without channels or in closed channels, and more so in channels containing the heat-supply pipes, will inavoidably result in thawing and sagging of the channel's bed. As shown by the experience in using such networks in Noril'sk, the zone of thawing frequently extends to the ground bed of the building resulting in their considerable deformation.

Even more faulty was the solution adopted in designing the surgical building in Yakutsk (Fig. 57). The building has 11 lead-in places. The sewage and heat-supply pipes are laid in wooden, unispectable chest in the

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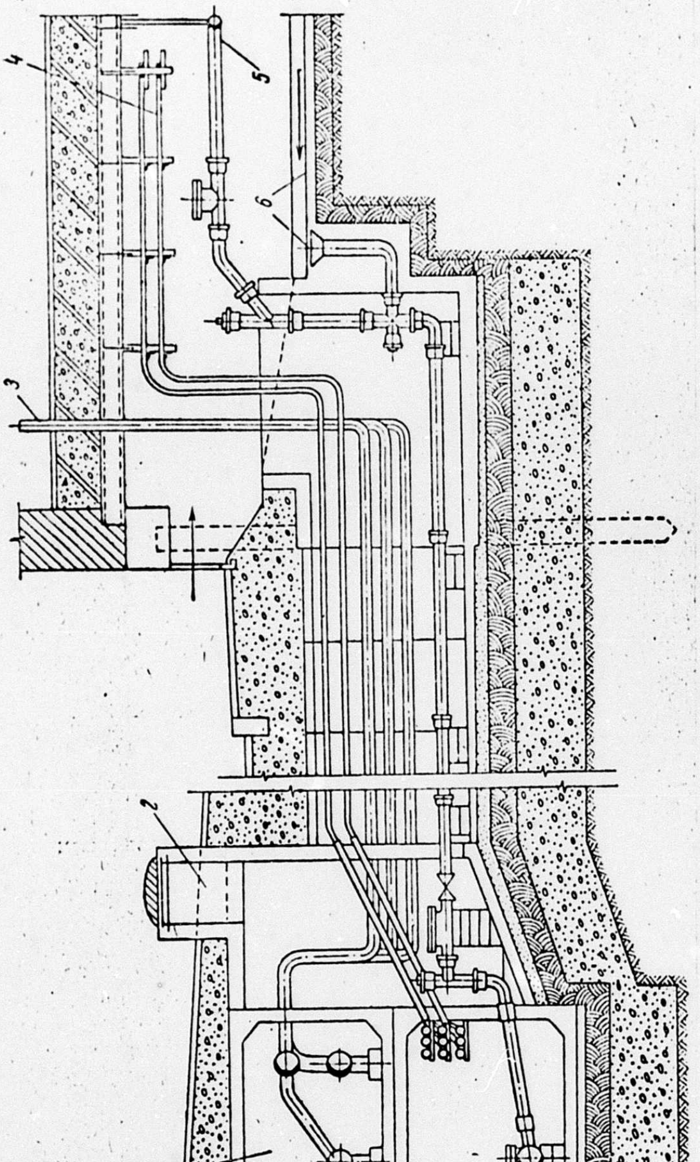

Fig. 55. Lead-in of engineering utilities into the building's basement

1) street header; 2) manhole for inspection; 3) lead-in of heat supply; 4) separation of cables; 5) separation of sewage pipes; 6) trough in the basement

6—А. П. Кушнев.

ground near the building. Since it is possible for water to drip from the building into the cellar, such a location for outdoor pipes creates conditions favoring the thawing of the ground bed and, therefore, may deform the building. In designing ventilated cellars under buildings of Noril'sk and Dudinka, their ventilation during the winter is given considerable attention; no partitions or other compartments that may obstruct the free flow of cold air are permitted.

Fig. 56. Lead-in of sewage pipes into building equipped with ventilated cellar

Fig. 57. Outdoor sewage system of Yakutsk surgical building
кол = header

For buildings located on a slope where the cellar in certain places had a height of more than 2.5 to 3 meters, an exception was made by building cold rooms with floors at the same level as the outdoor layout. In case the constantly used ventilation during the winter impaired the explotation conditions of the occupied quarters, a ventilated space was provided under the floor.

Fig. 58. Use of ventilated space under auxiliary compartments of Noril'sk residential houses

The use of cellars with ventilated space under the floor is permitted in residential houses of Yakutsk. For this, the ventilated space under the floor is about 50 cm in height, is located 1.5 to 2 meters below the layout mark, is waterproofed by a layer of tamped clay, and is ventilated by channels built in the wall of the building (Fig. 59). The fault of this design is the possibility of surface water penetrating into the basement during the spring and the snow blown in during the winter. There is also a possibility of the basement becoming clogged during the construction.

Fig. 59. Construction of cellar for Yakutsk residential house

The durability of Yakutsk buildings with ventilated basement inaccessible for inspection is explained by the lack of central city networks of sewage, water, and heat-supplying pipes. Such solutions are not acceptable in designing a well-arranged city.

Increasing the height of ventilated basements, use of lead-ins open at both ends from the street header to the basement, and locating the pipes in basement by suspending them to the ceiling -- this is the solution used in Noril'sk that can be recommended for the regions of the Extreme North to assure the durability of the erected buildings. Even the buildings erected in Noril'sk on solid grounds with buried ice remain durable when designed in this manner.

Chapter III

BUILDING PARTS FOR EXTREME NORTHERN REGIONS

pp 85-149

1. Concrete and Reinforced Concrete Foundations and Beams

Conditions Governing the Selection of Design

Foundation designs for the construction conditions of the Extreme North always depend on the geological structure of the foundation beds and on the methods employed for the erection of buildings. Conventional belt-type foundations (assembled of separate blocks, or monolithic) made of concrete are more suitable for carcassless buildings erected on rocks deposited to a depth of up to 2 meters. For deeper deposits of rocks, reaching in certain cases a depth of 20 meters and above, it is expedient to design column-type concrete or reinforced concrete foundations.

For buildings erected on thawed grounds or on beds composed of loose frozen grounds both the belt-type and the column type of foundations are suitable, while in certain cases the building may be erected without foundations on reinforced concrete plates laid on the surface, etc. During the last few years an ever-growing application was found for pile-type foundations, the use of which is so effective that recently it became the predominant type.

The design of foundations is closely connected with the design of beams for the column-type and the design of the grillages and beams for the pile-type of foundations. It is determined by both the most economical design and the working conditions, when the concreting of the grillage or of the beams performed during the winter season may require larger efforts and may even cause damages in the foundations.

All listed types of foundations and beams are also used for construction in the common regions of the country, but the severe climatic conditions and the pernafrost grounds of the Extreme North requires in many cases a change in their design. Different designs for foundations and beams are used in different regions of the Extreme North. The effeciency of any design depends to a considerable degree on the presence of an industrial base for the construction, supply of power, volume of construction, etc. Cited below are the widely used designs of foundations and beams for the industrial and civil buildings of Noril'sk, Dudinka, Yakutsk, Vorkuta, and other cities of the Extreme North.

Belt-type foundations

For the conditions of the Extreme North, belt-type foundations can be recommended only for carcassless buildings erected on rocky or thawed beds with

the foundations at a depth of no more than 1.5-2 meters from the surface of the earth or of the floor of the cellar. For deeper installations, the use of belt-type foundations is not economical due to the larger volume of work required for digging and concreting. For buildings erected by the method of preserving the permafrost state of the bed, belt-type foundations cannot be recommended also because the high heat-conductance of the concrete during the summer contributes to the pentration of heat into the ground which, by raising the temprature of the bed reduces its supporting capacity. In addition, belt-type foundations increase significantly the cost of the protecting structures (walls) of the ventilated space under the floors and impair its cooling conditions during the winter season.

Lately, however, for building in the areas of the Extreme North on loose frozen and also on large-skaleton thawed and swollen grounds use is made of reinforced concrete belt-type foundations installed to a minimum depth (up to 50 centimeters), or even on the surface. The depth in this case may depend only on protruding corditions of the grounds, or on the designs of the buildings. Taking into account the fact that loose frozen grounds subjected to artificial thawing without commpressing the ground when the building is erected without preserving the permafrost state of the bed may experience large saggings, the designs of the foundations and buildings must assure their durability when the expected saggins take place.

As an example is the two-story service building of the Noril'sk mining-emergency station (Fig. 60). The building is erected on a belt-type reinforced concrete foundation of 50 cm in height. The depth of 30 cm in the ground for the foundations is required by the design to provide an entrance for the motor cars. The foundation height of 50 cm was used to assure rigidity for the building in the sections between the joints for sagging, which are provided at each 20-39 meters along the length of the building. Such a design prevents the formation of cracks in the walls due to a irregular sagging of the foundations.

Fig. 60. Sectional view of Noril'sk mine-emergency station
1) reinforced concrete belt foundation

Rigidity of the building in its 3 dimensions is provided by joining the longitudinal foundation parts at the sag-joints (space between walls to reduce the effect of sagging) with lateral belt-type foundations. The two-side reinforcement (upper and lower) of the foundation parts enables them to sustain the positive and negative bending moments, both of which may appear at the section near the sag-joints due to an irregular sagging of the bed.

Similar foundation designs are also used for many other buildings in Noril'sk. The large reduction in cost and in the time and labor spent for the work make it possible to recommend the use of reinforced concrete belt-type foundations installed to a shallow depth and with the walls cut into separate rigid blocks, provided they serve for the erection of carcassless buildings on non-swillen grounds, including the carcassless buildings erected in accordance with the method of subsequent thawing of the beds and an assumed sagging of up to 20-25 centimeters.

Construction on a large scale of two-story wooden buildings without foundations is going on in Vorkuta. Afill of 30-50 cm of large-skeleton soil covers the ground on which the building is supported. The floors of the first floor are heated. The height of the ventilated space under the floors is 30 centimeters. The heat and water pipes are laid in chest on the surface of the earth. Such a design assures the durability of the two-story buildings erected on non-swollen grounds, reduces considerably the cost and expenditure of labor, and can be recommended for use in other regions of the Extreme North, where the laying of supplying pipes on the surface is permitted.

Column-type Monolithic Foundations

The depth of foundations using the method of preserving the permafrost state of the grounds is established in accordance with the NiTU (standards and specifications) 118-54, part IV, table 4. In buildings constructed by this method, however, there were frequently cases when due to defective exploitation or construction (damaged pipes, temporary flows of water during the construction, spring-season waters reaching the foundation cavities, etc.) local thawing exceeded considerably the depth of the effective layer. The recurrence of such factors is fairly possible, therefore, they must be taken into account in designing buildings.

At the same time, as shown in table 12, part V of Nitu 118-54, the calculated resistance of solidly-frozen grounds during the explotation of the building increases significantly with the drop in temperature of the grounds at the level of the foundation's foot, which usually can be obtained by using a larger depth for the foundations.

Taking all this into consideration, In Noril'sk it became necessary to disregard the recommendations of NiTU pertaining to the determination of the depth for installing foundations (in Noril'sk and Dudinka the standard depth for foundations was 3-3.5 meters) and to use for the construction of major buildings the principle based on increasing the calculated resistance of the solidly-frozen grounds of the bed. This reduced to a considerable degree the probabilty of deformations at a slight increase in the cost of the foundations. In certain cases of large loads this solution proved to be more economical, since the larger resistance of the bed made it possible to reduce considerably the area of foundation pit and of its supporting part.

Particular caution is needed in determining the foundation depths at places used for the water, sewage, and heat-supplying pipes entering the building. Observations carried out in Noril'sk for many years indicate that, even when these pipes are located in ventilated, open at both ends, reinforced concrete channels, the thawing under the channels extends to a depth of 2 and more meters. This made it necessary to increase the depth at such places up to 2 meters above the usual depth.

This was not taken into accountby the plans for Yakutsk. In the future, the need of municipal improvements will make it necessary to abandon the laying of such pipes on the surface and to switch to underground locations; this will be difficult to accomplish due to the inadequate depth of already installed foundations.

During the early period of planning for Noril'sk and Dudinka, wooden gratings or pads of sand were installed under the concrete or concrete-rubble foundations, as recommended by NiTU 118-54, part III, par.23. Experience, however, has shown that the use of gratings or of sand pads in many cases is not a matter of necessity, it only increases the costs considerably due to the need of deeper foundation pits and to the need of thawing and drying the sand pads during the winter. more than that, in many cases the use of wooden grates impairs the structure. Their loose contact with the foundation bed due to the uneveness at the bottom of pit or the use of round timber for the grates will result in larger tensions and, therefore, in foundation saggings.

In erecting concrete or concrete-rubble foundations directly on the surface of the grounds, if the concrete is heated electrically or the foundation pits are kept open during the summer days until the concrete gains in strength, then the thawing of the grounds at the foot of the foundations usually does not result in saggings that may interfere with the subsequent work, while the permafrost state of the grounds can be restored before the foundations begin to support their loads.

The use of sand pads is necessary only for foundations erected on beds of buried ice or on grounds with large inclusions of ice. In Yakutsk, wooden grates are used without fail, even in erecting assembled reinforced concrete foundations; this increases without reason the construction costs, just at the heat-insulation of the ground surface in the space under the floors, as recommended by NiTU 118-54, part 37, par. V.

Monolithic concrete and reinforced concrete foundations are intricate and time-and-labor consuming, particularly when work is performed during the winter season. The heating of the laid concrete by steam, which is widely used in Yakutsk, is very labor-intensive, makes it necessary to build a double enclosure and install temporary steam pipes, or boilers of the locomobile type.

Most economical and least labor-intensive is electric heating of the concrete. Electrically heated concrete, however, gains only about 70% in strength (SNiP [construction standards and rules] chapter VI, part 2). From the wide use of electrically heated concrete in Noril'sk it was established that even this percent of gained strength is difficult to obtain. At low temperatures, the gain in strength is discontinued as soon as the heating is stopped During the winter season, foundations become covered with frozen soil and their bottom has all the time a temperature below zero due to its location amidst the permafrost grounds.

The part of the foundation projected above the ground may acquire the strength specified by the design during the spring-summer period; this can assure the durability of the building only in that case, if the fundation is not subjected to the full load required by the design before it acquires the strength specified by the design. Some part of the foundation located in the effective zone will be subjected to thawing during the summer, but the low temperature of the concrete will not provide the conditions required for a further gain in strength.

A study of column-type foundations with electrically heated concrete has shown a strength from 25 to 70% for the concrete located in the ground. The was one of the main reasons for the collapse of a section of a Noril'sk 5-story residential building which occurred in 1957 (see Fig. 108). At the present time, the design-strength of foundations using electrically heated concrete is obtained by using a grade of concrete with a strength higher than called for by the design. For example, the 150 kg/cm^2 grade of concrete is used when the design requires for the foundation body a concrete with a strength of 100 kg/cm^2.

The digging of foundations pits requires much time and labor. There are no mechanisms for improving the frozen grounds. The work is performed by pneumatic drills or by boring and blasting small holes. In order to reduce the volume of earth-digging, for construction in Noril'sk use was made of the method of pouring concrete without the encasing mold, i. e., the pits were dug on three sides to the size required by the foundation body. The place to be occupied by the foot of the foundation was widened (by underdigging). One of the sides of the pits was dug wider than the dimension of the foundation with an enclosing mold inserted there. This made it possible to inspect the surface of the concrete. However, the opening, first selectively and later of all foundations concreted without the use of enclosing molds, had shown that an absolute majority of the foundations had shoes with dimensions not specified by the design, while the height of the ledges did not provide the shoes with the strength called for by the design. The foundation columns proved to be so narrow that most of them had cross sections of no more than 50% of those specified by the design (Fig. 61). The strength of the concrete in the sections of the foundations in contact with the walls of the pits was considerably lower than that of the design.

With the concrete poured at temperatures of 35-40°, the listed defects were responsible for the thawing and collapse of the ground in the walls of the pits, which affected the dimensions of both the pits and of the foundations and earth falling into the concrete reduced its strength. To assure durability for the buildings, a considerable part of foundations had to be strengthened by rings of reinforced concrete and the remainder had to be concreted anew. The pouring of concrete for foundations by this method was later abandoned.

The high cost and the difficult work, particularly during the winter, make the use of monolithic concrete foundations unprofitable for residential cultural-general purpose and carcassless industrial buildings, which should be erected on piles or assembled reinforced concrete foundations. Monolithic column-type foundations can be permitted for use only for carcassed buildings erected on beds of rock or thawed grounds in accordance with the method requiring no preservation of the bed's permafrost state. In this case it is necessary to take into account the reduced strength of the concrete, depending on the method of pouring and the temperature of the surrounding grounds.

Fig. 61. Column-type foundations with concrete poured without use of molds. 1) actual; 2) as called for by the design.

Fig. 62. Assembled column-type concrete foundations. 1) joined with cement mortar; 2) view along a-a.

Assembled foundations

Assembled foundations were used in Noril'sk since 1939 during the construction of the buildings of the mechanical plant. The consisted of ordinary reinforced concrete shoes with the columns inserted into their cups. Their defect, although this design is still in use, is the difficulty of making one piece out of column and the shoe during the winter season.

Assembled column-type foundations made of concrete blocks were used for the construction of the 70-th street of the city (Fig. 62). Later, however, it became necessary to abandon this type of foundations for the following reasons. The joining of the blocks with mortar is very difficult. The deposited mortar froze long before the leveling. This resulted in seams 5 to 7 cm thick. It was very difficult to harden and increase the strength of the mortar. The foundations made of blocks joined by the method of freezing the mortar sagged considerably due to the thawing of the seams. During the autumn freezing of the ground, the forces due to swelling damaged the foundations not loaded with weight of the building.

Of the assembled reinforced concrete foundations used at the present time, economically more suitable are the ones developed by the Yakutsk project. It should be added that these foundations were used for many industrial and residential buildings of Yakutsk. Their repeated application and the desire to standardize the dimensions to help their production served as a basis for the types of the designs for foundations and gratings (Table 2). Foundations of this type can be recommended for use in the areas of the Extreme North, because they are deformed by the forces of swelling and they are less costly and less difficult to build than the monolithic variety. Their application, however, requires certain changes in their design.

Table 2

Assembled reinforced concrete foundations used in Yakutsk

Key: 1) foundation type; 2) sketch; 3) length, cm; 4) cross section of stem, cm; 5) dimensions of shoe, cm; до = up to,

The dimensions of the foundation shoes must in all cases be derived depending on the calculated resistance of the grounds. In determining the area of the cross section and the reinforcement of the foundation stem it is necessary to take into account the bending moment inavoidably created by the wind. In addition, in places containing underground pipes, the foundation depth must exceed the length of the assemnled foundations used in Yakutsk. This depth must be determined by the conditions existing in the construction area. In Noril'sk, the foundation depth at the places with underground pipes is not less than 7-7 meters. The use of wooden gratings should be avoided; they increase considerably the cost of foundations and impair the operating conditions of the structures,

Wall beams

Concrete column-type foundations and reinforced concrete wall beams are widely used in construction of multi-story buildings in Noril'sk, Dudinka, Vorkuta, Igarka, etc. (Fig. 63). In Yakutsk are widely used reinforced concrete, column-type foundations with assembled beams made into one piece on the supports, or with monolithic reinforced concrete wall beams.

Fig. 63. Concrete foundations and reinforced concrete wall beams of multi-story buildings

1) tar paper; 2) brick protection of the space under the floor; 3) sand pad; installed only on ice-saturated grounds.

In designing the wall beams and foundations in accordance with the data of NiTU (standards and specifications) the temperature stresses were not taken into account, because the distances between the "temperature seams" usually did not exceed the standard distances. However, the work performed in the regions of the Extreme North at low temperatures and the long duration of the frozen state of the effective layer create special conditions for the structures. The wall beams and foundations are subjected to temperature stresses capable of their destruction. After the electrically or steam heated concrete gains in strength and the structure is cooled, the temperature difference frequently exceeds 100 degrees. During this time the foundation stems are held tight by the practically incompressible frozen grounds of the effective layer. When a wall beam is joined as one piece with the foundations and the beam is at an insignificant height above the surface of the earth, the use of temperature seams at different foundations as it is done in Yakutsk (Fig. 64) will not reduce the temperature stresses.

Fig. 64. Temperature seams in reinforced concrete wall beams as made in Yakutsk

The above statement is confirmed by the fact that in certain buildings in Yakutsk, Noril'sk, and other cities where the wall beams are joined as one piece with the foundations, the beams and occasionally also the columns of the foundations contain cracks. Reduced temperature stresses, as it is confirmed by the practice in Noril'sk, can be obtained in the following manner. For performing the work, the plan should have a clause requiring that, under winter conditions, simultaneneous concreting of electrically or steam-heated wall beams may be performed only for separate sections not exceeding 6-7 meters in length, and in case of uncut beams -- only over one span. Pouring of concrete can be continued only after the concreted sections are cooled. The distance between temperature seams should not exceed 12-15 meters, and should not always be combined with temperature seams made during the laying of the walls. It is recommended to make such seams unser the windows with the wall cut only to the bottom of the sill.

Fig. 65. Formation of cracks in foundations and wall beams

In monolithic reinforced concrete wall beams separated structurally from column-type foundations by iron sheet gaskets or roofing material, no temperature stresses should appear (theoretically) during the concreting of the artificially heated wall beams, because of their ability to move along the foundation. In practice, however, temperature stresses do appear in the beams due to the non-horizontal position of the gaskets and their freezing to the bulk of the foundation. After the walls are erected, their action on the foundation is so pronounced that the force of friction eliminates the possibility of the beam sliding along the foundation. Temperature stresses are the cause of cracks formed in wall beams and foundations (Fig. 65). The size of the cracks makes it necessary to teinforce the structures. For example, the cracks

formed in the wall beams at the supports of 5-story buildings in Noril'sk made it necessary to reinforce the buildings with metal structures (Fig. 66).

Fig. 66. Wall beams reinforced by metal structures

Fig. 67. Foundation and wall beams reinforced by rings of reinforced concrete

The surability of the buildings was menaced even to a greater extent by cracks formed at the headstalls of the foundations. This made it necessary to strengthen the foundation columns with reinforced concrete rings. In certain cases, where the cracks in the wall beams appeared at the sipports, the rings were widened at the sides of the damaged beams forming thereby brackets to

support the undamaged sections (Fig. 67). It should be added that the temperature stresses which caused the formation of cracks in the foundation headstalls were one of the reasons for the collapse of a Noril'sk 5-story residential house (Fig. 108).

The following design were developed later to reduce the temperature stresses in monolithic wall beams and to avoid the formation of cracks in the foundations. In monolithic unout wall beams the temperature seams were made at intervals of 12-15 meters on brackets. Frequently they did not coincide with the seams in the brick wall, but were located in the span under the windows or the apertures. The design had a clause concerning the pouring of concrete for the wall beams (see above). The wall beam was separated from the foundation by gaskets made of two sheets of roofing iron or tar paper. The headstall of the concrete foundation was reinforced by horizontally located reinforcing screens (Fig. 68).

Fig. 68. Temperature-seam in monolithic wall beam
1) seam in masonry only to the bottom of the 1-st floor window; 2) two layers of roofing steel; 3) reinforcing screen of foundation headstall.

The use of assembled or of monolithic wall beams cut on the supports and the reinforcing of the foundation headstall reduced consideranly the formation of cracks in the beams and foundations, but cracks in the walls appeared at the places where the beams joined the supports (Fig. 69), in this case, at the most stressed places -- in the partitions. The formation of cracks can be avoided by inserting a gasket of roofing material between the beam and the wall (to provide a certain sliding motion during temperature deformations), and to install reinforcing screens into the masonry anove the support. By taking the steps listed in the recommendations made it possible to avoid the formation of cracks which could affect the durability of the buildings.

Fig. 69. Formation of cracks in brick walls at places filled by seams in the wall beams

2. Pile-type foundations

Use of pile-type foundations for grounds in permafrost state

Under conditions resulting from the permafrost state of the grounds, piles can be employed in the following cases.

1. For buildings and structures erected by the method of preserving the permafrost state of the foundation beds. In this case, the fitness of the piles is assured by their freezing to the frozen grounds.

2. For buildings and struetures erected on rocky grounds by the method based on the assumption that the grounds may thaw during the exploitation of the buildings. In this case, the loads of the building are fully transmitted to the rocky bed through the butt-end of the piles.

The horizontal efforts due to the winds and the eccentricity are absorbed by the piles rigidly joined to the supporting structures of the building.

Pile-type foundations can be employed also for thawing foundation beds; in this case, the design and the their operating conditions are the same as for conventional suspended piles.

According to the method of installation, piles are divided into two types.

1. Piles driven into preliminarily thawed grounds. As it is done in Noril'sk, Dudinka, and Yakutsk, the ground is thawed by steam passing through a "needle-tube" of 30-50 mm in diameter, depending the the depth of the driven piles. The lower end of the tube has an opening for discharging the steam.

The upper end of the tube (the needle) is connected to a rubber hose through which passes the steam under a gage pressure of 4-6 atmospheres. In fine-grained ice-saturated grounds, both the needle and the pile descend easily to the thawed depth. In more solid grounds, both the needle and the pile must be driven downward or lowered with the aid of a vibrating plunger.

2. Piles lowered into preliminarily bored holes. The piles are installed in accordance with the instructions for piles driven by the method of subsequent freezing the piles in the holes (see appendix).

The choice of design and dimensions of the piles depends on the method used for their installation.

The advantage of pile-type foundations to be lowered into preliminarily thawed grounds is that, in this case, it is possible to use piles with large cross sectional dimensions and, in cases of necessity, it is possible to use economical shapes, such as double T-sections, hollow, etc. But, as shown by the experience in work with piles in Noril'sk (from 1936 to 1950), the installation of piles preceded by thawing the grounds has also substantial defects. The installation of piles by the method of preliminary steaming is always connected with lengthening the time spent in construction, because loading of piles is permitted only after restoring the permafrost state of the grounds surrounding the piles. In this case, piles used in areas with grounds located in the zone of zero temperatures ranging above -1° (covering no less than 40-50% of the territory containing permafrost grounds) make it necessary to interrupt construction for 6 and more months. In addition, preliminary thawing with the aid of the steam needle is difficult and, at time, is impossible in the presence of boulders and fragmental rocks.

The advantages of using pile-foundations installed in preliminarily bored holes are due to the simplicity of operations. In practice, the piles installed in holes bored by cable-percussion rigs are lowered by the workers attending the rig. Electrical power is supplied to the rigs by a flexible cable. The cost of preparing the site for boring is reduced only to the cost of bringing the electric power lines. At the present time, foundations on piles installed in preliminarily bored holes are the only ones used for civil and industrial buildings erected in Noril'sk by the method of preserving the permafrost state of the grounds.

All buildings and structures erected on pile-foundations satisfy the requirements for durability and exploitation, which testifies to the correctness of their design.

Foundations for industrial buildings and structures

The use of pile-foundations in construction of industrial buildings and structures began in Noril'sk during the early years of its construction activity. The supporting capacity of the piles was determined by the stress allowed in the pile frozen together with the ground. The strength of the piles was determined in accordance with the standards and specifications in force at that time. Piles were lowered into the ground which was first thawed by a steam-needle. The buildings and structures described below can serve as examples of the designs used during that period.

Fig. 70. Longitudinal section of Noril'sk brickyard No 2
1) kilns

The Noril'sk brickyard No 2 had its building erected on fine-grained, ice-filled grounds. The designing and construction were completed in 1937-1940. The building has a ventilated space under the floors to a height of 1.2 tp 1.6 meters (Fig. 70). The length of the piles was in accordance with their supporting capacity resulting from their freezing to the permafrost grounds. In designing, two versions were under consideration: reinforced concrete or wooden piles. Wooden piles were selected, in view of the 10-15 years of service life expected for the brickyard.

Similar pile-foundations were used in constructing the temporary electric power station in Dudinka in 1938-1940, the district boiler rooms (Fig. 71), and several other industrial buildings. Pile-foundations which are installed by softening the ground with steam have found a wide application during the erection of engineering structures. In 1946, for example, the TETs trestle for the water line of the river Noril'skaya was erected on piles over a route consisting mostly of ice-filled grounds in permafrost state (Fig. 72). The same principle was used in 1946 for building the TETs trestle for removal of water and ashes, etc.

During a somewhat later period, the installation of piles as foundations with preliminary thawing of the grounds was widely used in construction of high-voltage lines, snow-protecting fences, bridges, etc. However, the difficult work of thawing the grounds, the presence in the soil of large pieces of fragmental materials, and also the unavoidable prolonged interruption of work due to the restoration of the permafrost state of the grounds made it in many cases unprofitable to use piles which are installed by preliminary softening the ground with steam.

For industrial buildings, the wide application of pile-foundations with preliminary boring of holes began in 1958. The piles are round in shape with 30 cm in diameter and a length in accordance with the planned design of the building. Examples of application of piles in practice for construction of industrial, warehouse, and engineering structures are given below.

Fig. 71. Noril'sk boiler room on wooden piles
a) sectional view; b)boiler foundation; c) foundation for pipes.
1) concrete grating; 2) pile.

Several warehouse-buildings are built on fine-grained, ice-saturated grounds. The buildings are unheated which helps to preserve the permafrost state of the grounds without the need of a ventilated space under the floors. The reinforced concrete piles serve also as the carcass of the buildin (Fig. 73). In view of the insignificant vertical loads, the depth used for the piles was based on the minimum distance necessary to seal the piles in the permafrost thickness of the grounds which can counteract the forces due to swelling during the freezing of the active layer, and on the magnitude required to absorb the normal efforts. By providing durability, this solution made it possible to reduce considerably the cost of the building and the work-intensity, as compared with warehouse of the same volume built on columnar foundations.

The building of the main step-down substation was built in a mountainous area on a site containing crumbling rocky beds with sheets of ice. The building is heated and, therefore, required a ventlated space under the floor (Fig. 74). In this case use was made of interconnected piles joined at the layout level by reinforced concrete grating on which are placed the wall beams. This design reduced considerably the labor efforts and the cost of foundations by 15-20%.

The building of the thermoelectric central station was built on reinforced concrete pile-type foundations on an area of fine-grained, ice-filled grounds by using the method of preserving the permafrost state of t he grounds.

Fig. 72. The TETs trestle for the water pipe of the Noril'skaya River
1) water line pipe; 2) bolt

Fig. 73. Warehouse of supply base, sectional view

Fig. 74. Building of the main step-down substation
a) sectional view; b) view along A-A

During the early stage of using pile-type foundations with the piles sunk into bored holes, it was assumed that structurally it would be more advisable to arrange the piles in two rows perpendicular to the axis of the wall, since, in this case, the displacement of the piles from the designed position, or the displacement of the wall can cause only a certain redistribution of the vertical loads among the piles without the appearance of other bending moments due to the eccentricity (Fig. 75).

Fig. 75. Pile-type foundations of thermoelectric station (TETs)
a) top view of driven piles; b) section 1-1.
1) for concrete; 2) reinforced concrete pile.

The cost and the work difficulties in erecting pile-foundations were both reduced considerably, as compared with the version originally designed by the Leningrad branch of Teploelektroproyekt (Thermoelectric Project) which specified column-type foundations. Such an arrangement, however, requires larger volumes of monolithic concrete.

The experience with sinking piles into already bored holes made it possible to prepare temporary instructions for work with piles under permafrost conditions of the grounds by the method of driving piles into preliminarily bored holes, which limit the tolerances permitted during the work (see appendix). These instructions are based on a possible displacement of piles during the work of up to ± 5 cm from the position specified by the design. In complying with this condition, it proved to be more expedient to arrange the piles in a single row and to the eccentricity into account for the design of the piles, rather than to arrange the piles in two rows with the outer facet of the grating protruding by 65-70 cm beyond the boundaries of the wall, which as a

rule, makes it necessary to sink the grating into the ground. This is connected with extensive earth-digging work and larger volumes of concrete and reinforced concrete, and there is also the danger of damaged foundations caused by the forces due to swelling of the grounds.

Fig. 76. Design of pile-foundations for carcassless industrial buildings

1) cover for space under floor; 2) upper boundary of grounds in permafrost state

Based on the experience with designing in Noril'sk of both unheated and heated industrial buildings erected by the method of preserving the permafrost state of the ground beds by using ventilated space under the floors, the following designs can be recommended for pile-type foundations.

1. For carcassless heated buildings the piles should be installed in a single row. The in-plan arrangement of the piles should be such that will make their axesto coincide as much as possible with the centre of gravity of the vertical loads (Fig. 76). Vertical loads applied outside the centre will create bending moments M_1 at the junction of the pile with the grating

$$M_1 = Pe_1$$

where P - the vertical load per pile specified in the design;

e_1- the eccentricity obtained from the displacement in the direction of design load from the vertical axis of the pile.

In designing the grating and its junction with the pile it is necessary to take into account the bending moment M_2 resulting from the permitted displacement of piles from their design-position during the work

$$M_2 = Pe_2$$

where e_2 - the magnitude of the permitted displacement of the pile from the position specified by the design during the performance of work.

Consequently, the junction of the pile and the grating is designed to take care of the forces in the section I-I (Fig. 77), namely, the vertical load P and the bending moment in section I-I

$$M_{I-I} = M_1 + M_2$$

The bending moment in the junction of the pile with the grating can be avoided by joining rigidly the cover above the ventilated space under the floor with the grating (preventing thereby rotation of the section) to assure the durability of the structures located above. In this case, the junction of the pile with the grating can be designed as a hinged joint. However, the experience with designing and constructing buildings on pile-foundations in Noril'sk proved that it is more advisable to build the covers from assembled plates resting on the grating in an hinged manner, and to join rigidly the piles to the grating to assure the durability of the structures located above.

A belt-type grating serves simultaneously as a wall beam supporting the structure located above and, in view of this, the mark for the top of the grating usually corresponds to the mark for the bottom of the assembled plate of the cover above the space under the floor of the building.

In determining the bending moment appearing in the piles, it is assumed that the entire load caused by the wind is transmitted uniformly to all piles of the building (for the assmbled components of the cover, this is obtained by one-piece seams of the joints) and is applied the level of the cover above the ventilated sub-floor space.

Fig. 77. Diagram of forces acting on piles arranged in single rows

a) diagram of normal forces; b) diagram of bending moments
1) the ground; 2) effective layer

The maximum bending moment in piles caused by the wind appears at the level of the surface of the permanently frozen grounds (the passive resistance of the grounds of the effective layer is nit taken into account, because the fine-grained, ice-saturated grounds have upon thawing an insignificant supporting capacity. At the same section (Fig. 77, section II-II), the pile is

subjected to maximum efforts, namely, the normal force P (the weight of the pile man not be taken into account) and the bending moment M_{II-II}

$$M_{II-II} = M_{I-I} + H\ell_1$$

where H - the horizontal load of the wind per each pile;

ℓ_1 - the distance from the bottom of the foundation cover to the upper boundary of the permanently frozen grounds.

Based on what was stated above, the appears the possibility of using piles with sections of unequal strength, namely, section I-I to absorb the force P and the bending moment M_{I-I}, which determines the required strength of the pile-grating junction and the outlet of the reinforcing fixturesof the piles; section II-II determines the cross section of the reinforcing fixtures for the part of the piles and the bench mark of the concrete subjected to maximum efforts; section III-III is acted upon only by the vertical force transmitted by the end of the piles to the ground.

The inequality of the forces acting along the length of the piles is taken into account in their design. According to the diagram of forces, in section I-I (Fig. 77), the outlet of the reinforcing fixtures for making one piece out of the piles with the grating occupies about 25% of the area of the fixtures in the section II-II, the section under the greatest stress. The fixtures of the lower part of the pile occupy about 50% of the area of the part of the pile which is under the greatest tension.

The supporting capacity of a pile is determined by the equation

$$P = S_m F_m + RF_1$$

where P - the vertical load per pile specified in the design;

S_m - the resistance by the forces resulting from freezing the permanently frozen ground to the side of the pile (table 7, NiTU 118-54);

F_m - the area of the side surface of the pile located in the midst of the permanently frozen ground;

R - the resistance of the permanently frozen grounds of the bed, as specified by the design (table 12, NiTU 118-54);

F - the area of the lateral cross section of the pile.

In performing the work, it is rather impossible to install the piles with their tops at the same height; it is also practically very difficult to obtain even the tolerances of $\pm$ 10 cm allowed by the instructions for work with piles under the permafrost conditions of the grounds by the method of inserting piles into already bored holes. Taking into account the difference between the marks for the tops of the piles, and also the role played by the rigidity and strength of the junction in providing durability for the buildings, the grating in Noril'sk are made of monolithic reinforced concrete. This assures the durability for the buildings and can be recommended for use in other regions of the Extreme North.

2. For carcassed buildings, the presence of large concentrated forces (normal forces and bending moments) make the interconnected arrangement of the piles necessary. Depending on the type of the building (heated and containing a ventilated space under the floor, or unheated) and on its design, the grate is either of the low-height type (Fig. 78) or the tall type of the variety of gratings used for carcassless buildings. The method used for calculating both the strength of the piles and the supporting capacity of the ground beds is not different from the method used for piles of carcassless buildings.

Fig. 78. Reinforced concrete pile-foundations for the columns of the building's carcasses
1) anchor bolts for securing the columns; 2) pad of slag used for swollen grounds

3. For engineering structures (high- and low-voltage networks, snow-protecting fences, etc.) the construction of foundations is in many cases extremely difficult. The construction of foundations with the piles installed in already bored holes served to lower the cost and make the work less difficult. For this reason, such structures as mentioned above are erected at the present time in Noril'sk on pile-type of foundations. As an example can be mentioned the connecting gallery of the mine 16-18. In this case, the piles serve simultaneously as the stands for the trestle, while the monolithic grate at the top serves as the foundation for the supporting structures of the gallery (Fig. 79).

In places where the height of the structure is such that the piles are unable to sustain the force of the winds, above the surface of the grounds are installed tie pieces for the winds (made of metal or reinforced concrete). In construction of snow-protecting fences, electrical transmission lines, etc., the piles serve at the same time also as the above-ground support for the structure. An efficient design that can be recommended for snow-protecting fences would be a combined structure consisting of reinforced concrete supporting piles and wooden snow-protecting shields (Fig. 80).

Fig. 79. Connecting gallery of mine 16-18

a) design of foundations, piles, and gratings; b) general view of the gallery; c) section 1-1; d) section 2-2.

Fig. 80. Snow-protecting fence on reinforced concrete piles a) general view; b) side view; 1) pile (S_1) diameter 30 cm length 800 cm; 2) pile (S_2) dia = 30 cm, length 400 cm; bracing.

Note: additional S_2 piles and bracings are installed only in those cases when the the length of the main piles does not provide the strength to withstand the winds.

Foundations for residential and general cultural service buildings

The use of pile-foundations for the wooden houses in Noril'sk and Dudinka which use piles installed in preliminarily bored holes began in 1936. For residential stone houses, pile-foundations were first used in 1943 (Fig. 81). The use of pile-type foundations was made necessary by the engineering and geological features of the construction site. Under a cover of moss vegetation was a very deep layer of fine-grained, ice-saturated grounds with separate inclusions of buried ice. When thawed, the grounds acquired the viscosity of a fluid.

When undisturbed, the thickness of the effective area varied from 40 to 60 centimeters. With the cover of vegetation removed, the seasonal thawing of the ground increased to a depth of up to 1.5 meters. The temperature of the ground in the zone of the annual zero-range amounted to -0.8^{o}. According to the standards (OST 90032-39) in force at that time, the erection of major buildings and structures on column-type foundation by using high-temperature, permafrost grounds containing ice-sheets and ice-lenses was not permitted, even when constructed by the method of preserving the permafrost state of the foundation beds. For this reason, such buildings were erected on wooden piles

with low concrete gratings. The latter was set to a depth at which its foot was located below the upper boundary of the permafrost grounds. The timber, due to its location in the zone of permanently frozen grounds, was prevented from destruction and from bulging out the foundation by the swelling forces of the grounds along the foot of the grating. The grating was made with sloping facets to reduce the forces due to swelling which acted upon the surface of its sides. The softening of the ground by steam and the installation of the piles were performed during the winter. For this, the pits for the gratings were left open during the entire period of subzero temperatures to assure the restoration of the permafrost state within 3-4 months.

Although the reliability of this method was confirmed by the exploitation of the buildings for many years, it should be noted that the building of foundations with wooden piles and low gratings is very difficult, it requires earth-digging operations for the gratings, it is non-productive and, therefore, cannot be recommended for future use; it is of interest only as one of the stages in mastering the installation of pile-type foundations for the areas with permanently frozen grounds.

The mastering of the installation of piles into already bored holes and the introduction of this method in the practice of building foundations opened wide prospects for productive erection of foundations.

The development of designs of pile-foundations for residential and cultural and general purpose buildings gave rise to many problems which were not successfully solved by the designs of the early buildings. Only by a thororough study of the experience with construction and exploitation of the buildings erected on pile-foundations it was possible to improve gradually the designs and to find the most efficient designs for pile-type foundations.

As an example are the early designs which are widely used at the present time in the construction practice of Noril'sk.

1. Two-row installation of the piles. The first 5-story residential buildings were designed with the groups of piles arranged in two rows (Fig. 82). Under each partition was installed a group of 204 piles. The advantage of this design is that no bending moment will appear in the junction of the pile with the grating in case the piles or the walls are displaced during their installation. At this, the jamming of the piles by the grating and by the ground makes it possible in calculating the force of the wind to consider the structure made of piles as a frame, which reduces the absolute value of the bending moment, as compared with the calculated wind loads applied to piles arranged in a single row.

The defect of this design is that, even by maintaining a minimum possible distance between the centers of the piles (3 pile-diameters) and taking into accounted the allowable tolerances, the width of the grating reaches 175-180 cm. At this, the grating extends beyond the dimensions of the building by 60-70 cm, which requires a deeper installation in the ground. Such a design requires an excessive volume of earth-digging and additional consumption of concrete and reinforced concrete for the erection of the gratings, foundation poles, and wall beams.

In view of this defect, pile-foundations with the piles arranged in two rows are not used at the present time in construction of residential, cultural and general purpose buildings.

Fig. 81. Pile-type foundations of 2-story residential building in Dudinka
a) top view; b) view along 1-1; c) view along 2-2: 1) reinforced concrete wall beam; 2) concrete headstall; 3) pile

Fig. 82. Two-row arrangement of piles
a) view along A-A; b) view along 1-1; 1) minimum of 3 pole-diameters.

2. Single-row arrangement of piles with grating on the surface of the grounds. This design was effected for several 5-story residential buildings in Noril'sk (Fig. 83). Its advantage is that it eliminates the necessity of setting the grating deep into the ground. In addition, the grating serves to a considerable extent as an enclosing structure for the spece under the floor.

The defect of this design is the need for building wall beams and larger consumption of monolithic concrete and reinforced concrete. In case of swollen grounds, this design may cause the destruction of the foundations. This was the reason for abandoning the use of such designs.

3. Single-row arrangement of piles with tall grating-wallbeam. This design is used at the present time for the construction of all residential, cultural, and general purpose buildings of Noril'sk (Fig. 84).

The advantage of this design is that it eliminates the earth-digging for the grating and requires considerably smaller volumes of reinforced concrete (no wall beams and foundation poles). The grating is separated by "temperature" seams in intervals of 12-15 meters to avoid the formation of stresses caused by temperature in the grating-wallbeam and in the piles. These seams do not coincide with the temperature seams of the walls, but are made under the window openings and the masonry is cut by the seams only to the bottom of the window sill.

Among the defects of this design is the monolithic form of the grating. The larger than allowed deviations in positions of the piles, both in plan

Fig. 83. Single-row arrangement of piles with reinforced concrete belt-grating

a) section a-a; b) front; c) top view along b-b; 1) front view; 2) assembled tie pieces

Fig. 84. Pile-foundation with grating-wallbeam

a) view along A-A; b) view along 1-1; 1) attached by welding to inserted parts; 2) enclosure of ventilated space under the floor; 3) bench mark of floor of ventlated subfloor space.

and in height, which inavoidably appear during the work do not, however, make it possible to obtain an efficient grating that can assure a rigid joint with the piles. This was the reason for using 50 cm as the height of the gratings, although a height of 25-30 cm would be acceptable constructionwise. This design is the most economical and can be recommended for use in the areas of the extreme north.

A maximum possible diameter of d = 35 cm for boring the holes, a thickness of about 2 meters for the efective layer in the area of the city, and a design-temperature from -1^{o} to -2^{o} were the parameters that determined the construction and dimensions of the piles frozen into the permafrost grounds. Under these conditions and in accordance with the specifications NiTU 118-54, the following were used for calculating the supporting capacity of the piles: $S_m = 1$ kg/cm^2 for calculating the resistance of the forces due to the freezing at the side surface of the pile by the permafrost grounds, and $R = 5$ kg/cm^2 for calculating the resistance offered by the frozen ground to the normal load.

The external loads which affect the design and dimensions of the piles were typical for residential 5-story buildings loads applied to partitions, namely, P 90 tons as the normal force, M_{I-I} 5 ton-meters as the bending moment at the junction of the pile with the grating, and M_{II-II} 10 ton-meters as the maximum bending moment at the level of the upper boundary of the permafrost grounds.

The desire to make full use of the supporting capacity of the piles acquired by the forces of their freezing to the ground in holes of specified dimensions was the factor that predetermined the round shape and the length of the piles. This condition is satisfied by arranging two piles (Fig. 84) of 39 cm in diameter and 7.9 meters long for each partition (pier?). In places for bringing the engineering utilities into the building, the piles had the same diameter but had a length of 10 meters, because the thawing of the grounds at such places usually is by 1.8 to 2 meters deeper than the depth of seasonal thawing.

The reinforcement of the reinforced concrete piles took into account the irregular distribution of the forces acting along the length of the piles by reducing the number of rods in the lower part and increasing the pitch of the spiral reinforcements. This made it possible to design types of piles for residential construction in Noril'sk (Fig. 85). The same types of piles were, as a rule, used in designing the pile-foundations for industrial, cultural, general purpose, and auxiliary buildings. To make it possible to measure the temperatures of the ground beds, in certain piles were inserted metal tubes of 50 mm in diameter.

The erection of buildings on pile-type foundations made it possible not only to provide durabilty to the buildings erected on the permafrost grounds of Noril'sk and Dudinka, but also to reduce sharply the cost and the labor-intensity of the work. Shown below are the technical and economic performances of two versions of foundations, wall beams, and enclosing structures of ventilated space under the floors, developed for a 5-story residential building containing 80 apartments in Noril'sk (Table 3).

A comparison of these versions shows that the use of pile-type foundations reduced the cost per 1 sq. meter of residential area by 39.6 - 29.3 =

= 10.3 rubles and the expenditure of labor by 2.12 - 0.272 = 1.848 man-days. Still more economical is the use of pile-type foundations in construction of low buildings, an example of which is the vegetable-storage building in the city of Dudinka.

The warehouse No 1 for the storage of 4,200 tons of vegetables is a one-story building erected on column-type foundations. The cost of foundations per 1 sq. meter of storage area was equal to 82.5 rubles. In 1960, began the construction of the vegetable-storehouse No 2 for 10,000 tons of vegetables which was erected on pile-type foundations at a cost of 25.4 rubles per 1 sq. meter of storage area.

Fig. 85. Reinforced concrete piles used in Noril'sk, d = 30 cm
Dimensions in parentheses are for piles 10 meters long.

1) spacing between coils

Table 3

The coas and expenditure of labor in erecting the foundations, wall beams, and the walls of the ventilated space under the floors of a 5-story, 80-apartment building in Noril'sk

key: 1) designs; 2) cost of work in erecting the structures, rubles;
3) total for the building; 4) per 1 sq. meter of residential area;
5) expenditure of labor for erecting the structures, in man-days;
6) Version I. column-type concrete foundations with monolithic wall beams and a 1.2-brick wall enclosing the space under floor. plastered on the outside.
7) Version II. Foundations consisting of piles 8 meters long and 30 cm in diameter with monolithic grating and reinforced concrete wall enclosing the space under the floor.

The significant reduction in cost and expenditures of labor had for its result the at the present time, in Noril'sk and in Dudinka, all buildings erected by the method of preserving the permafrost state of the grounds are built only on pile-type foundations.

New foundation designs in Noril'sk

The study of the experience with building and exploitation of buildings erected on pile-type foundations by the method of preserving the permafrost state of the ground beds served as a basis for improving further the designs and the work on piles and, correspondingly, for reducing the construction costs.

In Noril'sk, further investigation in the field of foundation construction proceeded in three directions:

a) performance of work -- mastering the boring of holes of large diameter;

b) possibility of using larger design-loads for the piles inserted and frozen in the permafrost ground;

c) development of new designs of pile-type foundations.

As a result of the carried-out investigation, it was possible to master the boring of holes of 45 cm in diameter with the aid of type-BS-1 percussive boring rig by increasing the diameter of the boring bit and solving the problem of its dressing. The larger diameter of the hole makes it possible to use piles of different shape and, instead of the presently used round piles with 30 cm in diameter, to employ piles of two types: round piles of 40 cm in diameter and square I-beam type measuring 32 x 32 cm with trimmed corners and with a diagonal length of 43 cm. It should be noted that in connection with the increase of the diameter of the hole to 45 cm, the output of the boring rig is reduced from 1 meter/hour for d = 35 cm to 0.8 meters/hour, while the the cost of boring 1 meter of hole is respectively increased.

A detailed study of the geo-thermal conditions of the ground beds of buildings and structures erected by preserving the permafrost state of the grounds made it possible to increase the magnitude of the forces (S_m) due to the freezing of the side surface of the piles to the ground by 20-25% without violating the requirements of Table 7 of NiTU 118-54.

Fig. 86. Diagram of design-forces acting on the piles by locating one pile under the pier of a 5-story residential building
a) diagram of normal forces; b) diagram of bending moments; 1) the ground; 2) effective layer

The hole with its diameter increased to 45 cm is optimal for construction of 5-story residential buildings, because the load applied to the piles makes it possible to use only one pile in each partition; at the same time it represents a minimum requirement, because if the piles are distributed more sparsely, the entire load of the partition will be applied to the wall beam, which will impair the structure.

Simultaneously with this, certain designs of residential buildings have been revised and this made it possible to reduce the design-load per

partition from 90 to 82 tons (by replacing the formerly used insulation with mineral felt and by using perforated bricks for the inside walls). The lower design-load, larger value of S_m, and the use of only one pile per partition of 5-story residential buildings made possible by using a larger transverse cross section -- all these proved the expediency of creating new designs for the piles of residential structures which, in strength, satisfy the diagram of forces (Fig. 86). At this, the production requirements and the allowable deviations remain as before (see appendix).

Fig. 87. Square, I-shaped pile (по = along)

The new design for the piles is based on the principle of using to a maximum the supporting capacity of the reinforced concrete. In sections I-I and II-II which support the full vertical design load and are acted upon by a bending moment, the pile has the shape of a square. Below the effective layer, where the bending moment in the pile is absent and the vertical load is reduced because a part of it is absorbed by the forces due to the freezing of the side surfaces, the cross section of the pile decreases and changes to an I-shape (Fig. 87). This design makes it possible to reduce the cross sectional area without reducing the side surface of the pile which freezes to the bed of the grounds.

The use of square, I-shaped piles with varying cross sections in construction of 5-story residential buildings in Noril'sk had reduced by 35% the cost of erecting foundations per 1 sq. meter of residential area, as compared with the cost of erecting round piles of 30 cm in diameter. Labor expenditures were also reduced correspondingly.

Design of piles for areas of the Extreme North

The wide application of pile-type foundations (particularly on a scale as practiced in Noril'sk and Yakutsk) had created the conditions favoring the use of certain types of designs for the piles. In Yakutsk, for example, where the wind forces are insignificant (and were not taken into account when designing residential buildings) and the low temperature of the permafrost grounds makes it possible to use for S_m (forces from freezing) a value considerably larger than in Noril'sk, and where the method of preliminary thawing of the grounds makes it possible to use piles of larger cross sections, use is made only of certain types of piles (Table 4).

Such piles are not suitable for Noril'sk and Dudinka, where the dimensions of the transverse cross sections are limited, the forces due to freezing are considerably lower than in Yakutsk and, in addition, the structures are to withstand the action of strong winds. This made it necessary for Noril'sk to create its own types of piles (Table 5) the use of which assured durability for the structures and reduced the costs and the time of construction. The cost of erecting foundations in the areas of the Extreme North, however, is still very high. This includes also the buildings erected on deeply deposited rocky beds by the method of subsequent thawing of the beds, etc. The next steps to be taken in order to reduces the cost of erection of foundations are:

1) mastering the boring of large-diameter (700-1200 mm) holes in permafrost grounds which will make it possible to use pile-stands for buildings erected on deeply deposited rocks and other beds which do not sag too much when thawed;

2) selecting an efficiently designed pile possessing a maximum freezing surface and using to a full extent the supporting capacity of the material of the piles.

In Noril'sk, at the present time are produced and experimentally tested piles of new types. The creation and use are dictated by the fact that, in 1961, large panels will come into use on a large scale for residential construction, including the panels made of gas-cinder concrete [gazozolobeton], which will reduce the load par partition (and per pile) by 15-20%.

Pile-type foundations for buildings erected by the method of subsequent thawing of ground beds

The preservation of the permafrost state of the ground beds during the use of heated buildings is always connected with considerable expenditures for constructing a ventilated basement or other structures. At the same time, the study of permafrost grounds makes it possible to determine with a certain degree of accuracy both the possible ultimate dimensions of the thawing bowl in the beds and also the magnitude of complete saggings. The use of pile-type foun-

dations makes it possible to construct a number of buildings on grounds the thawing of which results in saggings of 1 meter and even more, without affecting the building's durability and its exploitation. As an example are the hothouses under construction in Noril'sk.

Table 4

Piles used in Yakutsk

1) Type of foundation; 2) sketch; 3) length; 4) cross section
(до = up to)

According to the data of an engineering-geological survey, the beds under the building will thaw to a depth of 8010 meters, in which case, the complete sagging will amount to 80-100 cm. The building is to be erected on piles which also serve as the supporting carcass (Fig. 88). The design is based on two conditions: a) the design of the roof, walls, and joining places must assure the durability of the building in case of sagging; for this was

taken into account the possibility of correcting the deformed joints (by raising the girders and wall panels); b) the piles are designed for a supporting capacity based on the forces which will keep the lower part frozen as long as the thawing bowl does not spread over the entire depth occupied by the pile; and also on a supporting capacity due to the adhesion of the side surface during complete thawing of the ground bed.

Table 5

Piles used in Noril'sk

1) type of foundation; 2) round; 3) square, I-shaped;
4) sketch; 5) length; 6) cross section; (= along)

Fig. 88. Design of hothouses in Noril'sk, sectional view
1) glass work; 2) stands; 3) heating chest; 4) reinforced concrete plates;
5) fill of large-skeleton soil

Such a design makes it possible to delay the sagging of the pile up to the moment when no less than 0.7-0.8 meters of ground will remain in frozen state. During this time the upper layer will thaw and shrink; at this the sagging of the floors will reach 0.7-0.8 meters. The floors sre filled up to their design-level with large-skeleton soil which helps the beds to become more solid. Upon further thawing of the bed, the pile begins to operate as if it were suspended by adhesion to the thawed grounds and the magnitude of the subsequent saggings will be determined only by the sagging of the underlying layer of frozen ground, which will amount to 0.2-0.3 meters (allowable even for industrial buildings, see p. 44).

This design, compared with earlier designs using column-foundations and ventilated basements, made it possible to reduce the cost per 1 cubic meter of hothouse space from 20.2 to 12.4 rubles, or a reduction of 1.6 times. It is planned to use the same principle for the construction of several other warehouses and auxiliary buildings in Noril'sk and Dudinka.

3. Covering and Covers

Covering ventilated cellars

The presently used types of covers installed above the ventilated space under the floors have the following defects: inadequate heat-insulation (particularly in residential, cultural, and general purpose buildings) and the high cost and difficult work. In Noril'sk, Yakutsk, Dudinka, and in other towns, the following designs are used for covering the space under floor of major buildings.

Fig. 89. Monolitic reinforced concrete cover over a ventilated (open) cellar
1) gasket of tar paper;
2) flooring with wooden pieces along the pads;
3) 1 layer of ruberoid;
4) cement tie piece;
5) foamy concrete;
6) reinforced concrete plate

Fig. 90. Type of anchoring the covering reinforced concrete plates into the wall
1) sealed with M-100 cement mortar;
2) seam sealed with M-100 cement mortar;
3) anchors. a) view along 1-1; b) top view.

A monolithic reinforced concrete plate over a monolithic wall beam (Fig. 89) distributes uniformly the force of the winds over all foundations of the building and protects well its inside against drafts. The walls are supported on the horizontal surface of reinforced concrete wall beam and have no horizontal fittings for the covers, which increases their supporting capacity. The latter is very important for the masonry work performed during the winter, because the carrying capacity of the masonry during the thawing period will affect unfavorably the erection of four or five-story buildings. However, the difficulty of performing the work, particularly during the winter, and also the economic expediency forced the Noril'sk and Dudinka builders to abandon entirely the use of monolithic covers for residential, cultural, and general purpose buildings, while for industrial construction to use such covers only when its use in assembled form could not be efficiently effected.

In Yakutsk and Igarka, the use of monolithic covers over the open space under the floors of residential, cultural, industrial, and other buildings continues even at the present time, which could be explained mainly by the lack of a base for production of assembled reinforced concrete.

Assembled (precast) reinforced concrete plates laid over monolithic or precast wall beams make the construction work less difficult and economically they are more expedient than the monolithic structures. However, the work performed at low temperatures demands the fulfillment of certain requirements, the non-fulfillment of which impairs the design and the heat-insulating properties of the covers.

The conditions required to increase the rigidity of the building, particularly during the thawing period, to assure a uniform distribution of the wind forces over all foundations (piles) include covers of perfect monolithic form. In practice, however, it is impossible to obtain monolithic plates by concreting their joints at low temperatures. The surface of the laid plates is subjected to a temperature of up to -40° and lower (just as the temperature of the surrounding air) which freezes the concrete or the mortar before it sets in the seam. The warming up of the concrete in the seams is very difficult and expensive. The opening of covers disclosed the presence of many void places in the seams joining the plates and a lack of adhesion between the seam and the plates.

The conventional methods of anchoring precast cover plates in brick walls of the building do not assure rigidity for the building during the thawing period of the walls erected during the winter. This, under the conditions of the Extreme North, is of great importance, because the ability of the wall to withstand the wind forces is provided by transmitting the wind forces from the outside longitudinal walls through the covers and to the lateral walls, which can be attained only by making all plates into one piece to be joined with the walls of the building. The unavoidable thawing of one side of the walls of a heated building during the winter and the thawing of the walls laid during the winter with the arrival of the spring-summer seasons causes the walls to be deflected from the vertical line towards the outside. The principal task of anchoring the plates of all covers in the walls is to prevent this deflection. These requirements, however, are not satisfied by the designed types of anchoring (Fig. 90).

During the most important moment of the spring-summer thawing of the mortar filling the seam, the anchor is practically not secured in the wall.

This is confirment by certain cases of anchors pulled out of the joints of deformed walls. For the conditions of the Extreme North, the anchoring of cover plates in the walls should be rigid and prevent any shifts in the horizontal plane. This is necessary because in most of the cases the walls are erected at low temperatures, while strong winds are possible during the spring thawing period. The most reliable anchoring of plates to the walls can be obtained by welding the one side of the anchors to the lugs of the plate and to weld the other side to a metal strip inserted in the wall.

No satisfactory solution has been found as yet for the heat-insulation of the ventilated subfloor space. According to heat-transfer calculations, insulation with the aid of boiler-room cinders requires a layer of more than 60 cm, making the total thickness of the cover equal to about 100 cm and subjecting the supporting plates to large loads from the weight of the covers. The total covering height is somewhat reduced by using foamy concrete (a foamy concrete layer of 30-40 cm), but industrial buildings require autoclave-type of foamy concrete with a minimum strength of 25 kg/cm^2, otherwise it should not be loaded. What is needed, therefore, is to cover the heat-insulating layer with a reinforced concrete plate to support the load of the floors. The use of foamy concrete for heat-insulating the covers of residential buildings is also without satisfactory results. During the winter, foamy concrete can be applied only in form of finished blocks.

In laying the blocks of foamy concrete at the places occupied by joints, there are formed gaps of several millimeters, and occasionally larger gaps are formed when the edges are broken off; the filling of these gaps with warm mortar is impossible during the winter. Not only cold air, but also winds can penetrate through these gaps. The result is that the strong winter winds penetrating through the gaps in the enclosure of the subfloor space produce a draft through the floors which is so strong that it is felt inside the room. The temperature at the surface of the floor frequently drops below 0° with the appearance of ice, or even snow.

The attempt to seal off the joints with roofing materials also failed to produce the required results. Ice was formed in the heat-insulating layer destroying thereby its insulating properties. Moreover, the freezing and saturation with ice of the heat-insulator made of foamy concrete or of formerly used slag cotton caused their destruction. For example, upon uncovering the floors of certain buildings it was found that all that remained of the insulation was a mass of fine-grained dust. The destruction of the insulation made of foamy concrete and slag cotton occurred after 5-8 years of the exploitation of these buildings. The required temperature drops are not assured by covers insulated with glay-dust mixtures, which are widely used in Yakutsk.

To improve the heat-insulation, over the foamy concrete was installed a cement tie-piece insulated at the top by adhering roofing material. The work, however, was very difficult and increased considerably the cost of the structures, while during low temperatures of the outside air, the temperature at the floor level of a heated room remained below zero. To obtain a temperature of above zero for the ground floor, the latter was heated in certain places occupied by kindergartens and nurseries. Under the floor, on the top of the insulating layer made of wooden screens or laths are laid pipes through which passes the water returning from the heating system. It improved sharply the temperature conditions, but it cannot be recommended for use on large scale

as it increases the cost and makes the work more difficult. Also, the inspection, washing, and repair of the heating system requires frequent uncovering of the floors.

Fig. 91. Construction of cover over ventilated subfloor space used in Noril'sk for residential buildings

1) board flooring; 2) bolsters 5 x 7 (h)in intervals of 70 cm-7 cm; 3) layer of pergamyn with adhesion to the joints; 4) slag-cotton felt 3 layers over 6 cm-18 cm; 5) layer of pergamyn adhering to the joints; 6) multi-gap plate; 7) wooden small poles, d = 16 cm, h = 17 cm, in intervals of 100 cm; 8) along 1-1.

The following designs of covers will best assure the heat-insulation of buildings and reduce the cost of work spent for their erection.

1. For residential buildings: insulation with semirigid slag-cotton-felt plates in 2-3 layers, with each underlayer covered without fail by the subsequent layer. The wooden floors are to be laid on bolsters placed over wooden gaskets (Fig. 91). Floors constructed in this manner are used for all buildings in Noril'sk and Dudinka and, as proven by experience, the slag cotton-felt plates arranged in several layers, as a result of a certain compression and glueing (viscosity of the bituminous base), form a layer which is non-penetrable for air, non-hygroscopic, and heat-insulating. Also, the use of slag cotton-felt insulation made it possible to lower by 15-20 cm the height of the covering above the ventilated subfloor space and reduce thereby the work in erecting the walls of the building.

2. For cultural, general purpose, and industrial buildings: in building wooden floors, it is necessary to use covers of the same design as used for residential buildings (Fig. 91). However, in floors using brush-type plates of asphalt, cement, etc., a second supporting reinforced concrete cover is necessary, due to the inadequate supporting capacity of slag-cotton-felt. This increases considerably the cost of erecting the cover and makes the work more difficult.

For buildings with fireproof floors it is economically expedient to use foamy concrete for insulation and build a bed under the floors made of a monolithic reinforced concrete plate, the purpose of which is to protect the foamy concrete from crumpling caused by concentrated loads on the floors (Fig. 92). This method assures durability for the floors when using foamy concrete of low strength (5-10 kg/cm^2). The unavoidable work connected with the use of reinforced concrete monolithic plate, the work difficulties, and the cost which still remains high made it necessary to search for new designs, and

at the present time, there are designs of supporting panels heat-insulated by slag-felt to be used for covering the ventilated subfloor space of industrial, cultural-general purpose, and auxiliary buildings.

Fig. 92. Construction of covers above ventilated subfloor space for buildings with fireproof floors

a) read from top down: ceramic plate on cement mortar; precast reinforced concrete plate; waterproofing: 2 layers of pergamyn on mastic with seams sealed; slag-cotton-felt, 3 layers, 6 cm-18 cm each; pergamyn layer with seams sealed; multi-gap plate.

b) from top down: cement floor; monolithic reinforced concrete plate; foamy concrete; layer of pergamyn with seams sealed; multi-gap plate.

a) with ceramic floors; b) with cement floors.

The supporting structure of the panels is made of PKZh plates containing other parts inserted during their production. The PKZh plates are used due to the availabilty of finished metal shapes which favors the wide use for the structures (Fig. 93). The heat-insulating layer is attached below to the plate and is held in place by a screen into which is deposited a layer of mortar. Panels of this type can be produced with finished floors. The industrial potentialities in production and assembly of the panels, and also their lower cost (panel covers cost 60-65% of the cost of the covers shown in Fig. 92), favor their wide application in construction. The supporting structures of the panels can be revised, depending on the loads and other requirements of the design.

Good results have been obtained from the design of the cover above the ventilated space under the floor effected in 1958 for the Dudinka potato-storage building occupying an area of 4,000 sq. meters. The very strict requirements for the temperature conditions inside the storehouse (not less than zero and no more than 3° for the entire height of 4.5 meters of storaged potatoes) required a new design for the cover and for the heating system. In Noril'sk, for the first time was designed a heating system for warming the inside of the building with warm air pumped into the void spaces of the type-PTK precast reinforced concrete plates. Since PTK-plates are not intended for large loads, they had underneath a dense network of beams. The heat-insulating layer is located below under the plates (Fig. 94). Unobstructed passage for the air through the gaps in the plates was provided by nipples made of roofing iron installed in the openings at the joints between plates. The joints were sealed with cement mortar. The control of the heating system was automated to provide a constant temperature inside the building.

Good exploitation results, sharply lower consumption of metal (pipes) and cost of construction make it possible to recommend this design for covers above ventilated subfloor space for use in other areas of the Extreme North. In 1960, covers with the void spaces in the plates used for heating the buil-

dings were employed in constructing the 8000 sq. meter vegetable storehouse in Dudinka, the hothouses in Noril'sk, and many other buildings.

Fig. 93. Insulated covering panel above ventilated cellar

1) hanger; 2) inserts (4 pieces in each rib); 3) short angle; 4) angular rods along the panel; 5) read from top down: layer of pergamyn on mastic; panel; PKZh-plate 30 x 60 or 1.5 x 60; slag-cotton insulation; 1 layer of pergamyn; plastered with 1:3 cement mortar over a Rabitts screen.

Fig. 94. Cover heated by warm air above the cellar of Dudinka potato-storage building

1) read from top down: asphalt floor; precast reinfoeced concrete plates; air channel; cement floor; foamy concrete; precast reinforced concrete plates.
2) from top down: asphalt floor; plates with many holes; GP"; mineral felt; precast reinforced concrete plates; "R-B".

Fig. 95. Series 1-464-M covers above the ventilated space under the floors of large panel-buildings

read from top down:

1) floor boards; bolsters every 600-50 mm;
2) soundproof gasket; soft wooden-fibre plate; insulation ; steam-insulation; 1 layer of ruberoid; cover panel.
3) floor boards; bolsters every 700-70 mm; steam and water proof; layer of pergamyn with sealed joints; slag-cotton-felt with layer of pergamyn and sealed joints; cover panel; 4) not less than.

3. For residential buildings assembeled from large panels, in designing the covers for the ventilated spece under the floors, in order to obtain rigidity and durability for the entire building it is necessary to to select the needed parts from the standard components (panels and blocks) with which the building is assembled. This is particularly important in view of the availability of standard equipment produced by the industry in the plants which specialize in construction of homes assembled from large panels. However, the covers for the cellars of typical large-panel homes (1-464 and 1-335), which are in vogue at the present time, are not suitable for the conditions of the Extreme North.

It is rather difficult to regard as efficient the design of the covers for the ventilated cellars specified in the typical design of series 1-464-M large-panel residential house developed by the Kiev affiliate of Giprostroyindustry in 1960 for use in the areas of the Extreme North (Fig. 95a). Along the monolithic grillage of pile-type foundations are installed precast wall beams of very complex shape with insulating interlayers. The cover consists of two reinforced concrete supporting panels with an insulating layer of slag-felt between them.

In Noril'sk, the 1-464-M large-panel houses are made secure as follows: instead of separate wall beams specified by the design, use is made of mono-

lithic grating-wallbeams containing the inserts for festening together the panels. Instead of two reinforced concrete covering panels, there is only one lowere reinforced panel on which are also installed the air-passage blocks. (Fig. 95b).

This method makes the building more rigid by using gratings and wall beams made into one piece, reduces the cost by eliminating the use of a second panel, decreases the overall height of the covering, and provides access for repairing the damaged insulation. These are the basic requirements for designing covers for open ventilated subfloor space, as practiced in Noril'sk and in other cities of the Extreme North.

Coverings between the stories of buildings

The designs used in the areas of the Extreme North for the coverings between the stories of buildings do not differ from the conventional typical designs. All that is necessary is to use wherever possible precast reinforced concrete, because concreting during the winter is very difficult and increases considerably the construction costs. It is also necessary to take into account the difficulty of laying floors at low temperatures. Asphalt cools before it becomes level and it is impossible at low temperatures to prepare the floors made of brush-type, inlaid, or cement tiles because it is impossible to obtain a smooth surface (by tightening and leveling) when the cover plates are concreted due to the rapid freezing of the mortar and concrete.

In the unheated buildings of Noril'sk, the installation of floors was frequently delayed until the arrival of the summer, although the enterprise was already in operation. This made it difficult for both the construction and the operations of the enterprise. The difficulties connected with concreting and building floors during the winter are eliminated by using precast panels and covers with ready-made floors and finished surface. It is not by far always possible, however, to use precast types of structures for covering, particularly for buildings used for complex technological processes (ore concentrating and metallurgical plants, electric power stations, etc.), but the unavoidable use of cranes with large lifting capacity for the assembly of carcasses and equipment of such buildings make it possible to construct a new design of covers.

In rebuilding the Noril'sk ore-concentration plant, taking into consideration the possibility of using a high-duty crane for assembling the structures, it is planned to finish one of the covers of the main building, consisting of a reinforced concrete plate and supporting metal structures, in the warm part of the building which is accessible to the crane and install it in finished form (with the floors, inserted parts, rimmed openings, etc,) together with the metal structures (Fig. 96). The total weight of the assembled component of the cover is equal to 10-12 tons.

Such panels can be produced in the street during the spring-summer season where the use of a multi-story crane is possible, irrespective of the construction stage of the building; for this, the variety of types, difference in loads and in inserted parts will not make their production more difficult. In addition, in case of necessity, such panels can be mounted togheter with the equipment installed on them and enable the assemblers to perform their work before the construction of the building is over, provided the weight of

the panel with the equipment is within the lifting capacity of the crane. This method of designing covers and sites for industrial buildings should be widely introduced in the areas of the Extreme North.

In heated buildings using PTK precast plates for covering (particularly residential, cultural and general puropse buildings) there are observed cases of cooling of floors which, at times, is inadmissible in buildings. It is due to the fact that joints prepared in winter are not filled completely with mortar and cold air penetrates through the void spaces in the plates. To reduce the possibility of cooled covers, it is necessary to plaster the inside part of the masonry where the plate rests on the wall (can be made to freeze), or to seal tightly the joints. The openings at the butt-ends of the PTK plates should be sealed, which is best done at the plants making the reinforced concrete products. The space between the butt-end of the plate and the wall should be insulated at the air passages with construction felt and gaskets of roofing material.

Fig. 96. Ore-concentrating plant. Covering panel.
a) schematic drawing of the assembly site; b) view along a-a; c) panel 1; панель = panel.

Roofs for industrial buildings

The correct selection of the design for the roofs is of special importance in view of the conditions of the Extreme North. Unsuccessful selection of roofing designs caused the destruction of the reinforced concrete plates of the central thermoelectric station (TETs), deformed the girders of the electrolytic shop (see p. 18), created difficult operating conditions at the substation of the ore-concentration plant, etc. The precast reinforced concrete covering plates became quickly damaged in the smelting shop of the nickel plant and certain sections collapsed entirely, and the usefulness of the reinforced concrete plate of the roof is coming to an end and must be replaced.

In certain shops of the metallurgical plants the metal girders are affected by corrosion and require reinforcement. Intensive corrosion caused the collapse of the girders together with the roof. The cause in the majority of cases of deformations and destructions was the lack of materials capable of preserving the supporting capacities when affected by the unfavorable action of the surrounding medium and large deposits of snow on the roof at a lower level, which also contributed to the formation of condensates in the layer of insulation.

The painting of the metal structures to prevent their corrosion with varnish [Kuzbasslak] or with oil paints proved rather ineffective. The reinforced concrete structure of the roof were coated with asphalt as a protection against the action of the surrounding medium, but this did not prevent the destruction of the concrete. Antiseptics and paints failed also to prevent the destruction of the wooden structures in the electric-bath room of the electrolytic shop. The damaging effect of the surroundings on the materials of the structures is, of course, a phenomenom taking place only in the Extreme North, but the low temperatures and the long winter season contribute more than their share. For example, the paint on the metal structures of the roof (made and painted in warm rooms) became always damaged during the assembly, particularly at the places occupied by the electrically welded seams, the quality of which cannot be restored at low temperatures.

To prevent the roofing materials from the damaging action of the surroundings it is necessary, in addition to improving the corrosionproof coatings and additives to increase the resistance of the concrete affected by the environments, for the design to take into account the steps that may reduce the possibility of conditions favoring the destruction of the materials of the structures. For example, the destruction of concrete and metal in metallurgical shops takes place primarily in places where the structures are subjected to moisture. The most intensive destruction of reinforced concrete covering plates occurs in places for building indoor water drains, in places favoring the formation of condensates, places containing metal girders on supports adjoining the sections of outside walls where condensate is present, at the open passages, etc. The best method of avoiding the corrosion of materials is also good ventilation of the occupied quarters, which should be taken into consideration by the design.

Strong winds, snow storms, frosts, and the long winter season are the factors influencing the selection of the roofing structure. Several buildings, whose construction was completed at the beginning of the winter, were operating without roof until the arrival of the spring-summer season, because it is very

difficult to cover the roof with roofing material during the winter. In several cases of heated buildings, the insulation of the covers, the tightening, and the glueing of the roofing materials were performed during the winter, which increased the cost sharply and alterations during the summer became unavoidable.

The roofs insulated with slag and foamy concrete, which are used for low design-temperatures, due to their large weight make the supporting structures more costly. The use of slag-felt plates for insulation makes it necessary to build additional structures for supporting the cover of roofing materials, because slag-felt has no supporting capacity.

The severe climate which makes the performance of work difficult, the high cost of labor, and the need for reducing the time and labor spent in installing the structures reveal the need of new types of roofs for the areas of the Extreme North. New designs for roofs of industrial buildings have been developed in Noril'sk in 1960 and are now used for construction.

1. Cold roofs made of sheets of grade ABAT aluminum alloy in accordance with AMTU 252-57 (Aluminum metallurgical specifications). The design of the roof is in accordance with the handbook <u>Types of enclosing designs of roofs and walls of unheated industrial buildings made of corrugated aluminum alloy sheets</u>, published in 1959 by Gipromez.

The defect of the design is the difficulty of securing the aluminum sheets to the girders and the large number of joints needed in assembling the roof, which makes it difficult to obtain airtight connections. Its advantages consists of sharply reduced costs, less time and labor spent in installing the structures, and ability to work at lower temperatures. Cold roofs of aluminum sheets should be widely used for construction in the areas of the Extreme North; it is, however, advisable to change somewhat their design. Large one-piece roofing panels should be used instead of separate sheets.

2. Insulated roof made of aluminum sheets. The roofing panels are 3 x 6 meters in size and are made of corrugated aluminum capable of being supported by a span of 3 meters of slag-felt plates and a supporting sheet of corrugated asbestos veneer or galvanized iron (Fig. 97). This structure is economical and is not difficult to assemble. Its use makes it possible to perform successfully the work at low temperatures.

The metal used for the supporting structures, which in this case consist of light-weight rod-trusses and girders with a span of up to 18 meters, is nearly of the same amount as used for the reinforcement of the reinforced concrete structures of a roof extending over the same span. Since such panels are rather new in Noril'sk, it can be expected that several changes will be introduced in their design. However, roofing structures made of aluminum and insulated with slag-felt deserve, indisputably, a wide application in the areas of the Extreme North.

3. Roofs assembled from precast reinforced concrete plates for unheated buildings. The 6 x 15 and 6 x 3-meter PKZh plates which are employed for covering industrial buildings do not eliminate the need of cement or asphalt coating and glueing of roofing materials, which is difficult to accomplish during the winter. It would be more expedient to level up the surface of the concrete with cement coating at the plant of reinforced concrete

products during the concreteing of the plates and also to attach there the roofing paper. Such a method would make it possible (after the plates are assembled and the joints are sealed along the lower layer of the roofing paper) to spend a minimum of time to complete entirely the work of constructing the roof in winter time, and this is very important in view of the conditions of the Extreme North.

Fig. 97. Insulated roofing panels made of aluminum alloy corrugated sheets

a) 30 x 60-meter insulated panel: 1) corrugated aluminum 0.8 mm in thickness; 2) 5 x 10 cm block; 3) 10 x 10 cm block; 4) galvanized iron lining; 5) slag-felt;

b) supporting structure for girder spacing of 6 meters: 1) insulated panel; 2) rod-girder 6 meters in length; 3) girder or reinforced concrete beam;

c) version of enlarging the panels into blocks for 12-meter spacing of supporting structures;

d) version of enlarging panels into blocks for 18-meter spacing of the supporting structures. (По = along).

4. Roofs with precast reinforced concrete plates for heated buildings. For the roofs of heated buildings are suitable the PKZh plates insulated with slag-felt; the latter are recommended for covering the open ventilated space under the ground floor of buildings having fireproof floors (Fig. 93, p.114). In this case, the plant of reinforced concrete products should make the surface of the plates as even as possible (or apply a coating) and attach by glueing one layer of roofing material. The PKZh plates with a width of 3 meters are recommended as the most suitable type. Their application requires fewer joints, which is very important because the sealing of joints is very difficult in winter.

Covers for attics and roofs for residential, cultural, and general-purpose buildings

There is no difference between the attic covers and the roofs built in in the areas of the Extreme North and those built under ordinary climatic conditions, except for the stronger anchoring of the rafters in areas subjected to strong winds. The latter statement is illustrated by a case taking place in 1941, when a strong snowstorm pulled down the entire roof with its rafters from a residential building located on Zavodskaya street. Separate sections continued to be torn off the roof by snowstorms during the following years. Attics must also be protected against deposits of snow. For this reason, roofs made of slate, asbestos veneer, or of other materials for which the sealing of joints is difficult cannot be recommended. Roofs with roofing materials attached to laths proved to be unsuitable, because the glueing can be done only during the summer. The attempt to use a cement containing solvents for glueing during winter ended unsuccessfully. The tearing off of roofing paper during the snowstorms is a frequent phenomenom. Considerable advantages can be obtained by using roofs covered with iron. They provide the required airtightness in the joints and they can be installed at any time of the year. Strong winds and snowstorms, however, require a stronger attachment of the sheets to the lathing and a very good joint between the sheets. The roofs are made without drains, with open draining of the water.

The ever-increasing volume of large-panel construction in the areas of the Extreme North requires the creation of panels for roofs containing no attics. This would eliminate the need of coating and glueing the roofing material during the winter. These problems have not also been solved by the plan for series 1-464-M residential buildings revised for the areas of the Extreme North. The design of attic-less roofs adopted by this plan specifies a combined insulation of porous clay filler, slag-felt plates, a plate of porous clay filler with concrete, glued roofing material, and a vapor-insulating layer (Fig. 98a). All listed operations are to be performed after the installation of the covering panels, which is particulary difficult during the winter.

In using the design type of series 1-464-M houses for construction in Noril'sk, there have been developed two versions of roofs for attic-less buildings.

1. An insulated roof panel with a cornice (Fig. 98b) to replace the covering panels specified in the plan. The advantage of this version is that it eliminates the installation of insulation, coating, and glueing of roofing material, which are difficult to perform during the winter. In addition, it eliminates the cornice blocks. The unfavorable features of this version are: the need of preparing new types of panels (for this is adopted a thin-walled

corrugated design similar to the PKZh type of plates) and the presence of certain joints which create small brifges of cold and which make the construction of the panels difficult.

Fig. 98. Sectional view of roof without attic for large-panel series 1-464-M house

a) design of combined roof as per plan for type 1-464-M; b) proposed version of combined roof: 1) slag-cotton plates; 2) wall panel.

key: (read from top down)

(1) 3 layers of ruberoid over a layer of pergamyn on mastic; concrete with porous clay filler; porous clay filler on a slope from 140 to 270 mm; vaporproof: 1 layer ruberoid on mastic; covering panel.

(2) 3 layers of ruberoid over a layer of pergamyn on mastic; reinforced concrete corrugated panel; slag-felt; vaporproofing: 1 layer of ruberoid on mastic; dry plaster over wooden laths.

2. Panels with cornice and finished cover to be installed after completing the work on insulation of the covers. The advantage of this version is that it eliminates the coating, while the roofing material is glued on at the plant when the plates are made. At the construction site, only the joints are sealed and only the top layer of the roofing material is glued on.

The disadvantage of this version is that it requires the use of other types of roof panels and a larger consumption of reinforced concrete, although the latter is compensated in the house, as a whole, by approximately the same quantity of reinforced concrete saved by the revised design for the cover above the open ventilated space under the ground floor.

It is not yet possible to recommend either of these versions for building roof without attics for large-panel residential houses of the Extreme North, because neither the basic version of the plan nor the revised versions for Noril'sk (versions 1 and 2) have been tried out until recently. However, with respect to cost and performance of work, the version 1 is most suitable for the areas of the Extreme North (Fig. 98b).

4. Walls

Walls of residential, cultural, and general-purpose buildings

The high cost of improvements, engineering utilities, and of foundations in the ares of the Extreme North, the desire to shorten the length of the routes used by pedestrians -- these are the factors which determined the expediency of multi-story construction, which explains the predominance of buildings with 3 to 5 stories adopted for Noril'sk, Dudinka, Yakutsk, and Vorkuta. For buildings of this height it is profitable to take advantage of the supporting capacity of the walls and partitions. For the Extreme North, the design of the walls must satisfy additional requirements, namely, longer durability of the buildings and the possibility of their erection during the winter season. To this should be added that it is very difficult to put out fires occurring during the cold weathers, especially during strong snowstorms (snow clogging the access for the fire trucks, instantaneous freezing of fire hoses, rapid spread of fire during snowstorms, etc.) and for this reason the walls should be made of fireproof materials.

The wind loads affect very substantially the designs of the walls. For the 5-story residential buildings of Noril'sk it made it necessary to construct additional major transverse walls, because the principal transverse walls separated by smokestack and ventilation channels did not provide the durability necessary to withstand the wind loads specified by the design. At the time of strong snowstorms there is observed a sharp drop in temperature in the rooms situated at the windy side. This is particularly felt in brick and wooden houses which are not plastered on the outside. To moderate the cooling of the rooms of brick buildings, it is necessary to fill and seal more thoroughly the outside masonry joints (if the building is nor covered with plaster on the outside) and pay special attention to the insulation of the window and door blocks and the joints between the covers and the walls. For wooden houses it is advisable to insulate the outside with roofing paper with a subsequent sheathing with "vagonka" or asbestos veneer.

The difficulties experienced in performing the work limit the selection of construction methods. It is almost impossible to erect walls with concrete grout or with concrete containing no sand, because it is connected with creating conditions favoring the concrete gaining in strength at the low temperature of the air. The laying of brick walls and walls of large brick or slag-concrete blocks during the winter season is the cause of many difficulties and unpleasant consequences. It should be also taken into account that the

cost of walls made of bricks is excessively high, even in areas containing their own brickyards (Noril'sk, Vorkuta, Yakutsk). The need for creation of new materials for wall is self-evident, particularly for the areas of the Extreme North; in practice, however, it is still the same-as-before materials which are used in construction; it is necessary to search for better construction methods based on such materials.

At the present time, in addition to those already mentioned, there is experience with planning and construction of walls designed as follows.

1. Slag-gypsum walls lined with brick on the outside (Fig. 99) have been built for several 2-story residential houses in Noril'sk. The outside brick lining was laid on cement mortar. The slag-concrete was poured into an inside enclosing mold. The cost per 1 sq. meter of wall amounted to 60-70% of the cost of brick walls. The slag-gypsum solution became set at low outside temperatures. The exploitation of the houses proved the complete suitability of such walls for houses up to two stories high which are erected under the conditions of the Extreme North (the recommended height is determined by the grade of the slag-gypsum employed for construction in Noril'sk). The defect of the design is the large labor-intensity required for the work and the presence of "wet" processes.

Fig. 99. Slag-gypsum walls lined with bricks

2. Large panels made of light concretes (gas-cinder-concrete, concrete with porous clay filler, slag concrete) reduce considerably the construction labor-intensity, make it possible to do the work at low temperatures, and provide the needed rigidity and durability for the buildings erected during the winter season. The unfavorable feature of such panels is the large weight (4 to 4,5 tons) which results in very high cost of delivery to the areas of the Extreme North from the manufacturing plants located in areas with more moderate climate. Local production of panels is restricted in many cases by the presence of light inert fillers and by the high cost. The cost of panels varies in different areas. In Noril'sk, for example, the earlier plans for production of panels by using the porous clay filler obtained from a pilot

plant proved to be unprofitable; compared with brick, it increased by 25-30% the cost per 1 sq. meter of outside walls of heated buildings. However, with the "cinder-solution" unit going into operation for production of solutions based on the pulverized cinders taken from the hydro-cinder-removal unit of the central thermoelectric station (TETs), there appeared an opportunity of using for outside walls the panels made of gas-cinder-concrete. This can reduce to one-half the cost per 1 sq. meter of walls, compared with the cost of brick walls.

In 1961, plans were made in Noril'sk for mass-application in residential construction of outside walls of gas-cinder-concrete panels made from the cinder-solutions of the TETs. Large-panel houses will be built in accordance with the type of design known as series 10464-M by changing only the design of the roof and the cover above the open ventilated space under the ground floor. The panels have a thickness of 40 cm, including the outside coating layer of 2.5 cm thick. The coating layer is added to protect the gas-cinder-concrete against the harmful effect of the atmospherical phenomena. The gas-cinder-concrete used for making the panels has the following physical and mechanical properties: grade $R = 50$ kg/cm^2 with moisture of $W = 0\%$, $\gamma = 900$-950 kilograms per cubic meter, and $\lambda = 0.21$-0.23 (where γ is the volumetric weight and λ is the coefficient of thermal conductivity in kilocalories/meter·hour·degree).

Fig. 100. Panels connected to metal inserts, as done for large-panel, series 1-464-M, residential houses

a) top view: 1) outside wall panel; 2) inside wall panel: 3) 30 x 8 mm anchor of bar steel welded to the inserts of the wall panels; b) view along 1-1

In designing the houses it is necessary to take into account that large panels can be assembled only when the wind velocity does not exceed 12-15 meters per second (to enable the cranes to operate). This, in certain areas of the Extreme North, may cause idleness of up to 60-100 days per year. In addition, the use of panels requires that special attention should be given to the joints.

To obtain joints of good quality (in strength and to satisfy the heat-insulation requirements) it is necessary to use solutions that will make the work and gain in strength possible at low temperatures. Special attention should be paid to the method of making the joints which are effected by electric welding of the inserted metal parts. The strength of the joints (Fig. 100) in the existing types of designs is inadequate to prevent the deformation of

houses caused by unequal sagging of individual foundations. It is known that large irregular saggings of buildings are common in the areas of the Extreme North (Vorkuta, Igarka, and others). Also, large saggings are unavoidable in buildings erected on loose frozen grounds without preserving the permafrost state of the grounds. All this makes it necessary to obtain elastic joints for the metal inserts which, while not preventing the sagging of the building and the opening of the seams which secure the panels, would at the same time retain the durability of the building.

Still remaining unsolved for the areas of the Extreme North is the ventilation of residential houses. In opening the air-vent (small hinged window) the enclosures of the glass panes become covered with ice and are difficult to close. The air-vent frequently freezes to the transom and its opening may damage its glass pane or the transom. It is advisable that the plan developed for the series 1-464-M large-panel residential houses should provide ventilation where the air-vent should serve as an additional means of ventilation to be used only during the summer season.

The walls of industrial buildings

Up to the present time, brick still remains the principal construction material for the walls of industrial buildings; less frequently used are slag-concrete, sandless concrete, and timber in certain areas (Igarka). For unheated buildings, in addition to the above-listed materials, walls are also made of precast reinforced concrete panel-plates and corrugated iron. In erecting walls during the winter season, it is impossible to fill and seal the masonry seams due to the rapid freezing of the mortar. As a result, the draft at the time of strong winds is so large that in heated buildings there is an inadmissible drop in temperature; in unheated buildings with walls not thicker than 25-38 centimeters, the movement of cold air during the snowstorms is felt all over and makes the exploitation of the building difficult. As an example are the unheated smelting and refinining shops of the Noril'sk Copper Smelting Plant, where a large part of the walls had to be plastered and certain parts had to be insulated with cement-fibrolite plates. In addition to the listed defects, the use of bricks or blocks increases the weight of the building and the cost of foundations and carcasses.

The use of reinforced concrete, thin-walled, panels made it much easier to construct the buildings and it improved the conditions for exploitation. Panels, however, are used at the present time only for unheated buildings. Insulated wall-panels for use in industrial buildings have not been tried out as yet in the areas of the Extreme North.

The unfavorable feature of using large reinforced concrete wall-panels for unheated buildings is the difficult sealing of the seams, In Noril'sk, a good performance was obtained from walls made of corrugated iron. With seams of good quality, the walls are adequately airtight, their erection is less difficult, and make it easier to support the structures. The unfavorable feature of corrugated iron is its corrosion. In Noril'sk, under development at the present time are designs of cold and insulated wall-panels made of aluminum alloys insulated (for warm panels) with slag-felt. These, however, have not been tried out as yet.

A considerable saving in cost of walls of Noril'sk industrial buildings was obtained from the use of large gas-cinder-concrete blocks. The size of the

is based on the weight of up to 4.5 tons per block. The high strength of gas-cinder-concrete (the grade of the products obtained in Noril'sk from gas-cinder-concrete is from 50 to 75 kg/cm^2) makes it suitable for use as supporting wall-panels.

Filling the openings in windows of industrial buildings

In designing walls of industrial building for the areas of the Extreme North special attention must be paid to the filling of the openings in windows. The use of conventional transoms with duplex window panes irrespective of the size of the openings in the windows does not provide the required illumination. During the long winter, the surface of the glass becomes covered with ice and snow which form an opaque layer. The high moisture inside the heated buildings forms ice blocks which not only obscure the illumination, but also make it difficult to work near the gaps in the windows.

Such a phenomonom can be observed in the heated shops of the metallurgical plants in Noril'sk, particularly in the machine room of the TETs which is equipped with double metal transoms. The ice formed on the windows (Fig. 101) becomes water running on the floor. Ice deposits reduce drastically the temperature near the windo gaps, large masses of cold air are blown in through the gaps of the windows durin a snowstorm, and near the windows are formed sections with continuous vapors of steam. The inadequate illumination, the formation of ice deposits, dampness, vapors, and the harmful effect of drop in temperature had for their result that the largest part of the windows remain insulated with special mats during the entire winter season, or are filled by masonry.

Fig. 101. Ice deposits on window transoms in machine room of TETs

From what was said above, it is obvious that the filling of windows, as it is usually done for heated buildings under the conditions of the Extreme North, do not provide illumination and impairs the exploitation conditions.

Fig. 102. Design of experimental filling of window space for the machine room of TETs

a) general view of filling; b) section 1-1; c) glass-pane assembly; 1) window block; 2) glass-pane assembly; 3) wooden shaped block; 4) window frame; 5) packing items; 6) bituminous mastic (grade 2-3 of bitumen and 15% asbestos); 7) water glass glue (sp. gravity 1.35-1.36) and 14-15% (by weight) of sodium fluosilicate.

As an example is the experimental filling of window space for the machine room of the Noril'sk TETs. Instead of double metal transoms were installed single wooden transoms filled with glass-pane assemblies. The glass-pane assembly consists of two sheets glued on a wooden rack of 30 mm in thickness.

to make it more airtight, the rack is located 2-3 mm from the facets of the glass and the space between the facet and the rack is filled with petroleum asphalt. In installing the glass-pane unit it is very important to obtain a maximum airtightness for the joint, which is achieved by filling the seams with bitumen or with a special mastic (Fig. 102). The experience with the performance of the window spaces filled with glass-pane assemblies proved that it eliminates the icing of both the outside and inside surfaces and the glass remains transparent. The window spaces with double metal transoms (Fig. 101) and with glass-pane assemblies (Fig. 103) have been photographed at the same time.

Fig. 103. Window space in TETs machine room filled with glass-pane assemblies

Based on the experiment which was carried out, it was decided to replace the double metal transoms with single wooden ones filled with glass-pane assemblies and, later, to use transoms with glass-pane assemblies also in other industrial buildings. The use of glass-pane assemblies immproved considerably the working conditions inside the building, eliminated the icing, but did not, however, eliminate the drafts though the joints between the glass-pane assemblies and the transoms.

Chapter IV

BUILDING STRUCTURES FOR THE AREAS OF THE EXTREME NORTH

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1. STONE STRUCTURES

Bricklaying

The presence of brickyards in several areas of the Extreme North (in Noril'sk, Vorkuta, Yakuts, and others) and the absence of industrial bases for the production of new types of materials made of stone are the factors which predetermine for the next few years the wide use of bricks for residential and industrial construction in these areas. The erection of brick walls and also walls from large blocks of bricks (which are extensively used for construction in Noril'sk) under the conditions of a long period of continuous low temperatures is connected with many difficulties. However, the necessity of unterrupted construction and putting to use the whole year round of residential houses and industrial enterprises makes it necessary to perform the bricklaying during the winter season (up to 70-80% of the entire volume).

The heating of large quantities of bricks or large blocks of brick for laying is unfeasible in practice. Bricklaying with the aid of electric heating makes the work more costly and more difficult. With frosts ranging below -35 to -40°, the mortar in the seams freezes considerably sooner than a section heated by inserted electrodes is completed. It becomes necessary to heat the brickwork with hot water or steam before the current begins to flow. Electric heating in bricklaying requires a large consumption of electrodes, electric power, and does not assure a uniform heating of all sections. In Noril'sk, where electric power is considerably cheaper than in other areas of the Extreme North, electric heating was abandoned even for the erection of such unique structures as the smokestacks of 100 to 150 meters high. Electric heating in bricklaying was effected in Noril'sk in 1940-1941 for the construction of the smokestack of the nickel plant and for the supporting walls of industrial plants.

The use of usual antifreeze additives, such as potassium chloride and sodium chloride, results in an insignificant gain in strength by the mortar, both before it freezes and when already frozen. With the air at low temperature, its freezing, as in case of ordinary mortar, begins before it becomes set. For this reason, the strength of the laying performed with a mortar using the mentioned additives is practically not higher during the thawing period than in the case of ordinary mortar. The effect of these additives on the mobility of the mortar at low temperatures is also insignificant. Their use does not eliminate the heating of the mortar. Because of the high hygroscopicity of the mortar, the walls become very moist during their first few years in use which impairs their heat-insulating properties, and this is particularly unfavorable in view of the conditions of the Extreme North. In using mortars containing additives, it will form deposits of salts on the walls.

Other types of chemical additives are not yet used for construction in the areas of the Extreme North; the additives listed above increase the cost of production, offer no advantages for performing the work, provide an inadequate increase in strength of structures during the thawing period and, therefore, cannot be recommended for use in the areas of the Extreme North.

Bricklaying in temporary enclosures can be justified only for certain unique structures. In Noril'sk, temporary enclosures were used only for laying fireproof bricks for metallurgical furnaces and smokestacks. The experience with construction proved that bricklaying during the winter should be performed by using warm mortar. However, with a frost of 35 to 40 degrees below zero, it is impossible to spread even heated mortar over the wall and, more so, to fill up vertical seams. The mortar freezes as soon as it is applied on the wall. Especially difficult is to deposit a uniform layer of mortar with a seam of required thickness when dealing with large blocks of bricks. To this should be added that, as a rule, there are no thaws during the long winter in the areas of the Extreme North; therefore, there can be no sagging of the lower sections during the thawing period that can be caused by the softening of the mortar. It is only natural that in such cases the sagging of walls is large during the thawing. The latter is very well illustrated in residential houses in which the rooms are divided by partitions one story in height which, with the arrival of the spring-summer period, were subjected to thawing on both sides. The walls sagged to such an extent, that the cement-fibrolite partitions became deflected on one side by up to 10 cm.

It should be pointed out that the use of bricks in combination with large brick-blocks previously made at the plant, in which the mortar has already the specified strength, will cause in one of the walls (as it is foreseen in typical plans for residential houses) the formation of vetrical cracks. It can be frequently observed that both the bricks and the blocks break over an entire section and the cracks reach a height of several tens of centimeters. Similar cracks can be also observed on sections of blocks. Their formation is explained as due to the irregulal sagging of the mortar along the wall which results in bending of the blocks. These phenomena reduce substantially the supporting capacity of the walls, affect the rigidity of the buildings, and in certain cases result in destruction of the walls. It is particularly important to take into account the difficult conditions of the Extreme North when solving the following problems required by the design of stone structures.

Joints between cover-plates and walls of multi-story buildings

During the construction of multi-story residential houses there were cases of destruction of brick sections and, occasionally, also of cover-plates at places where there was an adequate margin of strength according to the calculations. These phenomena occurred more frequently in the partitions of the inside longitudinal wall.

The upper part of the wall was resting with its edges on the cover plate, while its middle part was resting on the bricks (Fig. 104). A part of the wall supported by the reinforced concrete plate had one seam within the height of the cover-plate, while the middle part had three to four seams for the same height. This, during the thawing of the mortar, caused a larger sagging of the laid bricks at the middle part of the wall and resulted in cleaving at the place where the laid bricks rested on the plates. The destruction of the laid bricks at the resting place was so large that it required a temporary bracing during the thawing period and a subsequent reinforcement of the partitions.

Fig. 104. Reinforcing the brickwork at the supports of the plates (1) wrong; (2) correct; a) outside wall; b) inside wall; 1) cracks formed by thawing; 2) anchor; 3) insert of warm concrete; 4) heat-insulating gasket; 5) concrete insert.

The destruction of the brickwork, and occasionally of the hollow cover-plates, can be also observed in the outside walls. As an example is the deformation of the first-floor separating walls of residential buildings in Noril'sk. During the spring-summer thawing of the walls erected during the winter (the temperature in two days rose from minus 10-15° to +10°) the walls of the first floor began to bulge and the brickwork became laminated at the same time by vertical cracks (Fig. 105). The destruction of the walls was prevented by installing wooden stands on wedges which absorbed the load of the cover-plates and of the tie-pieces above the windows, and also by using temporary jackets for the walls. The deformation was so extensive that certain walls had to be taken apart and put together again. Several walls went through an injection procedure (grade 100 cement mortar was forced into the brickwork). The structure was kept in an enclosure for a duration of 10-15 days at the outside temperature of the air ranging from 10 to 15 degrees. The consumption of mortar used for injection was equal to 0.35 cubic meters per 1 cubic meter of brickwork, which describes the extent of filling the seams of brickwork erected at low temperatures.

A thorough study of the causes of the destruction of the walls had established that:

a) the actual stresses in the walls of the first floor dis not exceed the calculated resistance of the brickwork during the thawing period;

b) the bricklaying of the first floor was effected during severe frosts, therefore, the thickness of the seams was below the norm and the seams were inadequately filled with mortar;

The brickwork was simultaneously subjected to thawing on both sides and, due to solar radiation, the thawing was more intense on the outside.

Fig. 105. Damaged walls of the first floor of residential homes in Noril'sk

Fig. 106. The sagging of seams of outside brick walls caused by thawing. 1) wall beam.

The sagging of the brickwork seams on the outside part of the wall at the level of its adjoining the cover-plates and the tie-pieces above the windows caused the vertical forces to shift their line of action to the inside face of the wall; this increased the eccentricity of the load, which explains why all deformed separating walls were bulged towards the outside by 10-15 cm. The absence of monolithic feature and of resilence in the brickwork at the moment of thawing caused the lamination of the wall and its damage. The larger

thickness of the seams and the plasticity of the thawed mortar caused the loss of rigidity; the load of the upper floors caused the brickwork of the floor to sag unequally (Fig. 106).

The following construction methods are recommended to prevent deformations and damages at the places where the covers join the walls and in the separating walls of the first floor of multi-story houses, when the bricklaying is performed during the winter season.

1. At the place where the cover-plates rest on the inner wall or on the wallbeam supporting the inner wall, the section between the plates must be filled with concrete inserts (Fig. 104) and not by bricks; the plates of the adjacent spans must be secured together with anchors or twist joints.

2. At the place where the cover-plates rest on the outside walls, it is desirable when the acting forces are large to add to the thickness of the plate an insert of warm concrete or a ceramic block. In certain cases it is sufficient to verify the supporting capacity of the brickwork by assuming that the effective section of the wall is the thickness from the butt-end of the plate to the outside face, and by taking into account the eccentricity which has been formed. In this case, to prevent the damaging of the brickwork above the plate, or to prevent the crushing of the plate, it is advisable to leave a gap above the plate in form of a clearance insulated with building-felt. The strength of the brickwork can be increased by reinforcing it with netting at places where needed acording to calculations.

In carrying out during the winter the bricklaying of multi-story, carcassless buildings, particular attention must be given to the methods of joining the transverse walls with the inter-floor cover-plates which rest on the longitudinal walls. On one side is required a rigid joint between the plates and the transverse walls, because the entire force of the wind is transmitted to the transverse walls only through the cover-plates (which explains the need of joining the plates into a monolith of good quality). On the other side, the thawing and sagging of the brickwork of the transverse walls (when the enterior heat is on) will occur before the thawing of the outside longitudinal walls which, due to their frozen state, will not be affected by sagging during this time. Even more dangerous is that, during the spring-summer thawing of the outside walls, there is a possibility of a vertical shift by the cover-plates caused by the sagging of the outside walls; this will affect the rigidity of the joint between the cover-plates with the transverse walls. In such a case, if the plates are located so that a part of them enter the brickwork of both the longitudinal and transverse walls, the irregularity of the sagging will unavoidably damage the walls or the covers.

To obtain a rigid joint for the transverse walls of the building and the plates resting on the longitudinal walls, it is necessary (in case of one-sided thawing of the brick walls) to leave during the bricklaying a clearance of not less than 5-10 cm between the side-facet of the plate and the transverse wall. At the level occupied by the covers in the transverse walls should be inserted wires protruding by 6 mm every 15-20 cm. After the thawing of the walls of the building is ended, the clearance between the plate and the transverse wall must be made into a monolith by concrete.

Joining the outside and inside walls of carcassless buildings

Many buildings are completely erected during the winter and the inside finishing work is also completed during the winter season. Such buildings compose 70% of all buildings under construction in Noril'sk. The inside finishing work is performed with the heating system in operation. At this time, the inside walls are completolt thawed, become sagged, and the mortar at the seams acquires the strength required by the design. The thawing depth in the outside walls during this period usually does not exceed 5-10 cm, but due to the low temperature, the mortar in the brickwork gains little in strength, even after its thawing.

In the majority of cases, the sagging of the brickwork of inside walls will not result in cracks at the places adjoining the outside walls, if the thawing is gradual. The horizontal seams of the inside walls become distorted (Fig. 107a).

In many cases, buildings in a state as mentioned are put to use following the completion of the finishing works. When suddenly warmed by the arrival of the spring-summer season, the sunshine which may last the whole day and the effect of the interior heating create conditions which effect the thawing of the outside walls within 2-3 days. In such a case, the temperature of the thawed mortar still remains low and its gain of strength is proceeding at a very slow rate. During this period is observed a sagging of of the outside walls caused by the contraction of the seams and cracks are formed in the inside walls where they join the outside walls (Figs. 107a,b).

The reinforcing nets inserted at the joining places in accordance with the specifications for bricklaying in winter are unable to resist the breaking away and to prevent the formation of cracks. The longitudinal reinforcing net becomes either broken or is pulled out of the not-yet hardened mortar of the seams. In upper floors, such cracks reached 10 cm in certain cases. The strength gained to a certain extent by the mortar inside the surface of the outside walls and in the inside plaster-work, the incompletely filled sections of the seams, and the zero-strength of the thawed mortar serve to create conditions favoring the deflection of the walls in outward direction. At the same time, the combined brickwork of the outside walls (made of large brick-blocks and pieces of brick) loses its rigidity and its monolithic properties.

The loss of strength by the brickwork of the walls during the thawing period was the second reason for the collapse of a section of a 5-story residential house in Noril'sk during the spring of 1957 (the first reason was a damaged foundation). The heating of the house began several days before the arrival of the spring thawing. This caused the joints to lose strength at a time when the mortar in both the outside and inside walls had its least strength; the exessive local stresses in the walls, particularly at the places supporting the plates, exceeded the supporting capacity of the walls during the period of thawing (Fig. 108). If the walls of the building were to posses the strength and rigidity specified by the design, the damaging of a single foundation would have resulted in certain deformations and in localized damaging of the structures, which could hardly spread beyond the boundaries of the first floor.

Fig. 107. Cracks in brick walls due to one-sided thawing
a) sagging of inside wall: 1) mortar frozen; 2) mortar is set; 3) thawed inside wall; b) cracks due to spring thawing of outside wall

Fig. 108. Collapse of section of 5-story residential house in Noril'sk

To prevent the collapse of those buildings which have been constructed under the worst working conditions and of the thawing of walls with a design similar to the design of the damaged house, the following steps have been taken for the reinforcement of the structures.

1. Taking into consideration that the anchoring of the inter-floor plates into the longitudinal walls is unable to prevent the deflection of outside walls caused by thir one-sided thawing, anchoring drawing rods have bee installed in the plane of the inter-floor covers of the third and fifth floors where the outside and inside walls intersect each other (Fig. 109).

2. During the thawing period of the brick walls, the building was reinforced with temporary wooden structures (stands, props) which absorbed both the vertical load and the wind pressure.

3. With the wall sagging coming to an end, the gaps formed at the joints of the outside and inside walls were filled with mortar for a better transmission of the wind pressure by the longitudinal to the transverse walls.

4. Following the thawing, the walls were checked for their ability to absorb the entire force of the winds; for this, consideration was given only to the sections between the inner facets of the outside walls. In certain cases, the inadequate strength made it necessary to erect, instead of partitions between the apartments, solid walls on the first and second floors of the buildings under construction.

The newly designed buildings were based on the worst combination of possible factors and on bricklaying under winter conditions. For the floors

Fig. 109. Anchoring walls with the aid of drawing rods

a) top view oflayout of drawing rods; b) part A;
(1) level of clean floor.

subjected to large loads, the mixed laying of large brick-blocks and single bricks is not permitted to avoid the formation of cracks caused by thawing. In view of the difficulty of laying by using only brick-blocks, the walls of the first and second floors are erected in Noril'sk by using conventional methods. In addition, contrary to the direct instruction of the typical designs of residential 5-story buildings (series 447, 446, etc.) which forbids one-sided heating of the buildings, there is introduced one-sided heating to be effected without fail and to include also the lower floors. The purpose of this step is as follows: at the moment the thawing affect the outside walls and their breaking away from the transverse inside walls is possible, the latter had already gained in strength and are able to assure the durability of the building subjected to large wind forces. In case the strength specified by the design proved to be inadequate to withstand the pressure of the wind, which was the case for the mentioned series of the types of designs, the thickness of this walls was made larger within the boundaries of the first and second floors.

The correctness of the taken steps is confirmed by the fact that in the residential 5-story buildings constructed and put to use during the last few years there was not a single deformation which threatened the durability of the building , or which would reqire the reinforcement of the structures.

Brick walls with pilasters

The reinforcement of supporting walls with the aid of pilasters, which is widely used for ordinary construction conditions, during the 20-year period of construction in Noril'sk caused twice the collapse of the roof-structures of the buildings. At this, one of them (in the building of the locomotive station) collapsed after 8 years of use, and the other (in the building of a 60-car garage) collapsed during the first spring-summer thawing. The design of the brick walls with pilasters was in accordance with the standards and specifications and included checking without fail the strength of the brick-work during the thawing period. The metal girders for the roof of the station rested on the brick pilasters of the wall which were structurally made as for the 60-car garage (Fig. 110). The location of the support for the roof's girder on the pilaster was chosen with the aim of reducing the eccentricity due to the combined effective loads on the brickwork.

The collapse of three adjacent girders of the locomotive station was caused by the destruction of the pilaster. An examination of the remaining pilasters disclosed the presence of cracks at the places where they joined the walls of the buliding. The cracks which appeared in the concrete pad were traced in the brickwork by 50-60 cm. The dirt in the cracks testified to the many years of their existence. The initial formation of cracks pertains to the period of the first thawing of the inner surface of the brick walls. The pilasters laid during the winter were affected by thawing, because their surfaces located inside the building were warm, when the mortar of the brick-work of the outside part of the wall was still frozen, The sagging brickwork in the pilaster caused the latter to break away from the reinforced concrete supporting pad. The pad became converted into a bracket pinched in the wall which was not yet affected by thawing; it created in the wall a large bending moment and large shearing forces. The reinforced concrete pad, which was not designed for such efforts, detached itself at the facet of the outside wall and found itself resting again on the pilaster; this increased the sagging of the latter and caused the upper part of the pilaster to break away from the

wall. The stress in the brickwork of the pilater during the thawing of the mortar was much larger than the allowable stress. Later, the mortar in the brickwork and in the wall reached the strength specified by the design and this prevented the a collapse. While the building was in use, the pilasters located near the doors were frequently subjected to the action of the vapors from the locomotives and to freezing when the doors remained open for a long time. This resulted in damaging the plaster and the surface of the brickwork followed by their scaling. The action of the wind pressure and of the temperature stresses on the girder was transmitted to the wall in form of horizontal stresses and, as a result, the crack between the wall and the pilaster became larger, which caused the collapse of the girders supporting the roof.

Fig. 110. Joining the cover with the walls of 60-car garage in Noril'sk
(1) view along a-a; (2) top view along b-b.

The damaging of the pylon and the collapse of the roof of the building of the 60-car garage resulted from the following. Here, as in the previous example, the metal girders of the roof rested on brick pilasters. The bricklaying of the walls was performed during the autumn and only the part of the wall with the pilasters were exposed to freezing. Due to an oversight, the reinforced concrete pad was installed without the upper reinforcing items, as specified by the design; the electrically heated concrete of the pad did not acquire the strength specified by the design; in addition, the girders were installed on the supports by welding the anchor bolts to the supprting sheet of the girders.

During the thawing of the walls, due to the inadequate strength of the concrete of the pad, the entire vertical load of the girders was transmitted to the anchor bolts which had the form of -shaped rods to make them more secure in the plate. As a result, the weak concrete of the pad was cut by the horizontal part of the anchor. The inadequate binding in the brickwork (first along the line of the anchor bolts and then also along the plane of the supporting structure of the girder) caused the pilasters to break away from the walls which became damaged. It is typical that the collapse of the roof occurred at two different sections of the building. One of the girders collapsed in the span adjacent to the butt-end wall of the building, and two girders collapsed at the opposite part of the building. The collapse of the second section occurred two days later after the collapse of the first section. The causes and the nature of the collapses are identical in both cases.

Extensive deformation of brick walls with pilasters, which threatened the durability of the building, took place in a two-story warehouse. The supporting structures of the building were designed in form of one-story reinforced frames to make the first floor rigid. The rigidity of the second floor was achieved by building brick walls with pilasters resting on a cover made of reinforced concrete. The designers did not take into account the peculiarities of bricklaying performed during the winter in the areas of the Extreme North (the building was constructed in 1942-1943). With the arrival of the spring-summer thawing a crack passing through the wall was formed at the support-level of the pilasters; the crack was caused by the sagging of the lower part of the wall (Fig. 111). The pilasters hindered the sagging of the walls of the second floor, which appeared as if tho were suspended on the pilasters; as a result, the walls became deflected outwards. The collapse of the entire building was prevented in proper time by reinforcing the walls which were rebuilt during the summer.

To provide the strength and durability for brick walls with pilasters, it is necessary to bind well the brickwork of the pilasters to the brickwork of the walls, and during the winter, to install reinforcing nets reliably anchored into the wall. The design should contain a requirement for the bricklaying pattern which would specify the order of binding the brickwork of the pilasters with the wall. For the large vertical loads transmitted to the pilasters, it is necessary to install under the supporting parts of girders, beams, etc. reinforced concrete pads which could resist destruction due to the one-sided thawing of the walls. For this purpose, the pad must be designed for cases, when the heating of the building will cause the pilasters to thaw, while the outside wall remains in frozen state. In such a case, the pad operates as a bracket held securely in the brickwork of the wall. With the arrival of the spring and the thawing of the brickwork of the wall, the supporting plate subjected to a load will turn and will again locate itself on the plane of the pilaster which, having already gained in strength, will absorb practically the entire vertical load.

The reinforced concrete supporting pad must be installed deep over the entire thickness of the wall, except the outer lining having the thickness of one-half of a brick. To determine the bending moment in the pad, instead of calculating the distance from the place of application of the force to the plane of the pinched pad, use can be made with an adequate degree of approximation of the point of application of the load to the end of the pinched part of the plate minus the thickness of the pad (the minimum length of the pinched section). Since a favorable bending moment also makes its appearance during the simultaneous thawing of the entire brickwork, it is recommended to have

both the upper and lower zones of the pad reinforced symmetrically. None of the structures exerting a vertical load on the pilasters must be allowed to rest on the edge of the reinforced concrete supporting pad. The supports of the structures must be as near as possible to the axis of the wall. In all cases, the design of the wall with pilasters must take into account their sagging and weakening during the thawing period. At this, the loads affecting the pilasters only temporarily (load of the cranes, for example) may not be taken into account when calculating for the thawing period, but this must be mentioned without fail in the drawings.

Fig. 111. Formation of cracks in wall with pilasters during the thawing of the frozen brickwork

a) walls with brick pilasters: 1) dangerous crack; 2) safe crack; 3) pilaster; 4) reinforced concrete frame. b) wall with reinforced concrete columns: 1) column.

Framework-type of brick walls

The long duration of the winter season in the areas of the Extreme North makes it necessary to design supporting and self-supporting brick walls to absorb fully the design-loads during the thawing period of the mortar of the brickwork. This leads to an increased thickness of the brick walls whose strength after the thawing and setting of the mortar exceeds by many time the required strength. In addition, supporting and self-supporting walls operate poorly when subjected to winf pressures, because the brickwork is unable at that time to absorb the tensile stress during the bending.

All of these make it in many cases advisable to replace the design of supporting and self-supporting walls with framework-type of walls. However, the framework-type of brick walls subjected to freezing, when made to sag by thawing (which is very large in the polar regions) required rebuilding in many cases, even when its sagging stress was below the allowable stress, and at times, the walls collapsed due to large deformations. As an example are the individual cases in construction of industrial buildings which are described below.

The wall of the bunker building of the Noril'sk TETs had a height of 30 meters designed in form of metal framework filled with brickwork. Abutting against this wall was a ladder-type cage with supporting brick walls (Fig. 112). The framework walls and the walls of the ladder-cage were laid at the same time during the winter by following the method of "freezing". The spring-summer thawing began before the construction of the carcass was completed. Due to the large quantities of snow and ice accumulated inside the building and to the shadow location of the latter, the thawing of the walls on the inside surface was insignificant compared to the thawing on the outside.

At the expiration of 2-3 days began the deformation of the ladder-cage walls which broke away from the building and formed a crack extending through the wall by 40 cm to the top. To prevent a collapse, it was necessary to install emergency drawing rods to draw together the walls of the ladder-cage and the columns of the building's carcass. The deformation, however, continued and the tension in the steel drawing rods became so large that it clearly menaced to destroy the the carcass. To preserve the building and the adjacent structures, several hours had to be spent to dismantle completely the walls of the ladder-cage.

Exactly at the same time began the deformation of the framework-walls of the building. The more intensive thawing of the outsidr surface had created conditions favoring an unequal sagging of the seams along the thickness of the wall and caused thereby the walls to deflect outwards with a simultaneous formation of transparent gaps under the supporting cross bar of the framework. At this, a part of the brickwork (lining the cross bars) collapsed. The 6 mm reinforcing anchors, which were welded to the columns and cross bars to strengthen the anchoring of the winter brickwork, either broke or were pulled out from the seams of the brickwork. The collapse of the walls was prevented by installing temporary reinforcements and the intensely deformed sections were rebuilt during the summer.

Similar deformations occurred also during the construction of other industrial buildings in Noril'sk. During the construction of the main building of the ore-concentration and sintering plant, the thawing of the winter-laid framework brickwork was also accompanied with collapses of certain sections of the walls. It should be added that all deformed walls have been checked for strength and durability during the thawing; the work also included the installation of reinforcing nets in the corners and intersections of the walls and the reinforcement of the lower part of the walls of the ladder-cage. The strength of the mortar was high in accordance with the specifications, therefore, the cause of the above-listed deformations was not the violation of the specifications, but ignorance of the specific performance of brick structures to be expected under the conditions of the Extreme North.

The formation of inadmissible deformations in framework walls can be avoided by taking during the planning the following steps: the cross bars of

the framework exposed to the winds should be installed in height at spacings of not less than the distance which does not exceed ninefold the thickness of the wall. It is advisable to install the supporting cross bars at distances made necessary by the strength of the brickwork during the thawing. At this, the wind-exposed cross bars must be secured to the columns of the caecass in a manner that will enable them to shift freely in a vertical direction within the maximum possible distance covered by sagging during the thawing. The rigidity and design of the cross bars must assure the ability to absorb all wind pressures and to prevent the deflection of the brickwork from the vertical axis. Anchors of reinforcing iron must be welded to the framework cross bars for binding them to the brickwork. In certain cases, instead of wind-exposed cross bars, the brickwork can be reinforced over the entire span or wall by binding without fail the reinforcements with the columns of the carcass in a manner that will provide for the sagging of the brickwork and would eliminate the possibility of the brickwork deflecting from the facet of the column. The brickwork must rest with its entire section on the supporting cross bars of the framework.

Fig. 112. Schematic drawing of ladder-cages and framework of TETs bunker tier in Noril'sk

(1) the wall after thawing; (2) the wall in frozen state; (3) view along a-a.

It is advisable to reinforce the lining brickwork along the height of the supporting beam of the framework through every 4-5 rows by anchoring the reinforcing fitting to the cross bar in spaces of 1-1.5 meters along the length of the beam. The binding of the framework walls to the supporting walls of the building should not be permitted. The joints must contain without fail sag-proof seams. Taking into account that when height of the joined walls is large, the connecting item of the sag-proof seam will not be sufficiently rigid, it is advisable to effect the anchoring of the joined walls with temporary outside drawing rods which would allow only vertical sagging. The use of those measures taken in designing and constructing the framework brick walls of the industrial buildings in Noril'sk assued their durability and had eliminated dangerous deformations.

Brick smokestacks

The bricklaying of tall smokestacks under the conditions of the Extreme North is made difficult due to two basic factors: the wind pressures which are considerably larger than under ordinary conditions and the period of continuous low temperatures which is of excessively long duration. Naturally, none of the smokestacks installed by the method of freezing is able to withstand the strong pressure of the winds during the thawing period. In addition, the large and unequal sagging of the brickwork due to irregularity of solar radiations and thermal flows of air may, during the spring thaw of the mortar, cause the smokestack to lean and collapse even when there is no wind blowing. It is not, however, always possible to perform the bricklaying during the short spring-summer season. In Noril'sk, there is a vast experience with construction of smokestacks. Seven smokesracks 100-150 meters tall and a number of chimneys of smaller heights have been erected for the metallurgical plants and for the TETs. It should be stated that some of the construction stages have been accomplished during the winter season.

The construction of tall smokestacks was successfully effected in Noril'sk only because the designs of the chimneys and the plans for the organization of the work were developed together by taking into account the performance of the work at low temperatures. It was based on the study of the experience gaing in building the first smokestack in 1941. Several steps were taken for its construction, namely, warmed bricks, use of mortars with chemical additives, electrically heated brickworks, insulation of freshly laid brickworks, etc. This, however, did not assure the required filling of the seams to maintain the thickness prescribed by the norms and did not fully guarantee that the brickwork will acquire the necessary strength before the freezing of the mortar.

The many years of using the erected smokestacks confirmed the correctness of the adopted designs and work technology which makes it possible to recommend the employed technical methods for erecting tall brick smokestacks also in other areas of the Extreme North.

In designing the tall smokestacks, of the materials that could be produced by the local plants, the bricks of grade 150-200 and mortat of grade 100 were to be used to a maximum. The bricklayed was based on the grade of mortar specified by the design without taking into account the execution of the work during the winter season. The plan for organizing the work aimed to

Fig. 113. Temporary enclosure for construction of smokestack
1) section; 2) chambers for heating the bricks;
3) sand compartments; 4) winch; 3) hoist; 6) mortar joint; 7) cement storage.

accomplish the construction in a manner that would enable a section of the smokestack to become frozen only after the mortar acquired the strength specified by the design; this was achieved by building at the base a temporary enclosure for heating the bricks, sand, and water; there were also installed units for preparing the mortar and the hoisting mechanisms (Fig. 113). The steam heaters were located at the base and the shaft for the hoist was located inside the smokestack. The temporary enclosure surrounding the smokestack consisted of a light-weight metal carcass covered by canvass insulated with quilted cotton pads. Due to its own weight, the enclosure was in close contact with the smokestack (Fig. 114).

Fig. 114. Hoisting device used for building the smokestack
a) general view of device: 1) movable enclosure; 2) deck for bricklayers; 3) deck for fettling; 4) flexible connections; 5) rigid connections; 6) assembly 1. b) part of joined struts (of assembly 1); c) assembled flexible connections; d) assembled rigid connections. (1) strut.

The design of the hoisting device enabled the winch located below to lift the temporary enclosure, to build up the carcass of the shaft, and to raise the deck for the bricklayers. Irrespective of the winter temperatures, the enclosure made it possible to maintain in the working zone a temperature of the air of not less than 15-20 degrees. The size of the enclosure was sufficient for laying bricks to a height of 2.5-3 meters. This required two days of work for the lower part of the smokestack. During this time (with temperatures of 20° degrees for the bricks, 30° for the mortar, and 20° for the air in the enclosure), the mortar almost aquired the strength specified by the design, especially when an accelerant was added to the mortar. In laying the bricks for the upper part of the stack, which could be performed at the rate of 2.5-3 meters in height per day, the work was either deliberately interrupted, or the strength of the mortar was increased above that required by the design in order to obtain in one day the required strength. In practice,

there were cases of strong wind tearing off the enclosure; this made it necessary to discontinue the construction when the winds were too strong (Fig. 115).

Fig. 115. Smokestack of ore-concentration plant

Fig. 116. Installation of rings
a) general view; b) section; c) timber detail; d) installation of cantilevers.

The outside compressing metal rings were installed on the smokestack with the aid of suspended platforms hanging on the loops of the rings located below (Fig. 116).

Subjected during the entire time of construction to intensive heating on the inside (the minimum time required to complete the brickwork was 2 to 2.5 months for the lower part and 5 to 10 days for the upper part), the mortar of the brickwork acquired a strength which was practically above the strength specified by the design.

2. Concrete and reinforced concrete structures

In designing reinforced concrete structures, the commonly used methods when applied to conditions present in Noril'sk created a number of factors which made the work difficult. Certain methods, even the progressive ones, proved to be so difficult to accomplish that the work had to be discontinued

for a long time until the arrival of the spring-summer season, while certain structures could not be completed at all.

As an example is the span of the swimming pool in Noril'sk which was designed by the Leningrad branch of the Promstroyproyekt Institute. Accorfing to design, the swimming pool had to be covered by a thin-walled assembled covering roof. The production of the components of the covering roof consisting of large-size bent panels with an area of about 30 sq. meters was mastered by the plant of reinforced concrete products and a considerable part of the panels were ready for installation.

For supporting the covering roof was provided a monolithic reinforced concrete structure in form of an horizontal flanged beam with a span of 35 meters, resting with one belt on reinforced concrete columns and with the other on the walls of the building. The structure in absorbing the thrust of the covering roof would transmit it to the tie-beams located perpendicularly in the butt-ends of the tie-beam. The supporting structure and the tie-beams were concreted so that channels were formed in the belts. After the concrete acquired the necessary strength, through the channels were drawn reinforcing bundles of high-strength wires for withstanding the stress; this was followed by injecting cement mortar into the channels (Fig. 117). The difficulty of filling the channels during the winter in order to make monolithic the pre-stressed fittings of the supporting structures forced the builders to request the Promstroyproyekt to replace the pre-stressed fittings with ordinary intermittent section iron that would make it possible to concrete the structure at low temperatures by using electrical heating. Since the request for this change was rejected, the builders were unable to fill the channels with concrete during the winter and were forced to cover the building with precast reinforced concrete plates resting on metal girders.

Fig. 117. Supporting assembly for covering roof of Noril'sk swimming pool
1) channels for reinforcing wires.

Methods similar to those described above cannot be considered suitable for the areas of the Extreme North. Certain structures, which are economical under ordinary conditions, had to be redesigned and the consumption of materials had to be increased due to difficulty of performing the work during the winter. In the final analysis the construction was less expensive due to the simplified performance of work and the spending of less time and labor. The experience of many years in designing and erecting concrete and reinforced

concrete structures in Noril'sk, Dudinka, Igarka, and other populated places makes it possible to recommend for the areas of the Extreme North certain types of structures which are described below.

Monolithic structures

The preparation, hauling, and pouring of concrete during the snowstorms and low temperatures is extremely difficult. Still more difficult is to obtain the setting of the poured concrete. The use of temporary enclosures, storm jackets, and thermal enclosed mold increases considerably the cost of construction. The most widely used and simple method of providing the conditions necessary for setting, namely, electrical heating has a substantial defect because it does not assure a full gain in strength. In the technical specifications for production and acceptance of construction and assembling works of 1956, the appendix 8 to part III of SNIP (construction rules and standards) shows that the moment electrical heating is disconnected at maximum temperatures, the strength is from 70 to 90% of that specified by the design.

In performing the work under extremely low temperature and with winds present, the cooling of the structure is so considerable that it is impossible to obtain a strength of 90% at the moment the electrical heat is disconnected. This fact forced the designers of monolithic structures, in addition to specifying the grade of concrete, to put in the drawings instructions to use a higher than specified grade of concrete poured during the winter with the aid of electrical heating, when the full load is applied on the structure during the period between the time the concrete acquired a temperature above zero and the time it takes the concrete to bring up its strength to 100%. This method enables the concrete upon reaching a temperature of above zero to acquire the specified strength, but it increases the consumption of cement and the cost of construction.

In addition, in many cases of densely spaced reinforcing items or when inserted parts are present, there is a possibility of short-circuiting the electrodes which results in freezing the concrete. All of these testify that the use of monolithic concrete in the areas of the Extreme North should be reduced to a minimum. However, the less than full lifting capacity of the cranes of both the plants making precast structures and the cranes used for construction, the standardization of the types of products, and occasionally the structural requirements make the use of monolithic concrete unavoidable for certain structures.

The structures which are used depending on conditions required for installation, assurance of setting, and sizes can be divided into: massive structures (large foundations and supports), medium-size structures (beams and columns), and thin-walled structures (plates and partitions).

An example of massive structures are the piers of a reinforced concrete bridge and the foundations of smokestacks using concrete of 1000 cubic meters more in volume, both of these were constructed in Noril'sk. For concreting such structures was provided a peripheral electrical heating of the concrete, i.e., the electrodes made of bar iron were nailed to the sides of the enclosure. The making of working seams during the concreting was not permitted by the design. The laying of concrete proceeded day and night. The hauling and installation cooled the concrete whose temperature approached 0° at the end of

the installation. Intensive hardening accompanied with an abundant liberation of heat began when the electrodes were switched on. When the electrodes were switched off, the temperature at the surface of the massive structure was reduced to 2-5°. As a result of the large temperature drop there appeared in the concrete cracks due to sagging. By insulating the surface, the concrete reached 100% of the specified strength. Later, in order to reduce the temperature differential inside the concrete massive structure, in its middle part were left channels made of pipes or wooden ducts which made it possible to cool the inner part of the structure; by keeping the enclosure warm, it was possible to retain the higher temperature of the concrete at its surface. In this manner it was possible to reduce considerably the temperature differential and to prevent the formation of cracks in the concrete.

Under such conditions, a higher grade of concrete electrically heat when installed during the winter is not required to assure for it a strength required by the design.

In designing medium-size structures it is necessary to bear in mind that the long duration of the winter season and the continuous low temperatures create conditions at which conventional structures, even when conditions are provided to enable the concrete to gain the necessary strength, were destroyed and threatened the collapse of buildings. In Noril'sk, for example, several buildings had damaged reinforced concrete columns and cross beams of rooms located in the ground floors of residential, cultural, and general-purose buildings.

Fig. 118. Damaged columns and girders due to sagging walls
a) structure prior to being reinforced: 1) uncut reinforced concrete cross beam; 2) deformed girder; 3) assembled reinforced concrete columns; 4) cracks in column. 5) welded ties.
b) column reinforced by ring.

Particularly characteristic was the simultaneous destruction of columns and beams in three residential buildings which happened in Noril'sk during the spring of 1957. The walls of these buildings were erected during the winter. In the first floor, instead of inside longitudinal and transverse walls, the

could sag together with the wall (Fig. 120). The extent of sagging used by the design was the smallest of those used in Noril'sk since 1948 for work performed during the winter, i.e., 3 mm per 1 meter of height of the wall. Based on carried out observations, the sagging of winter-laid walls caused by thawing is in the Noril'sk area equal to 3-5 mm per 1 meter of height in the wall. The largest sagging which was taken into account by the design was 3.6 mm (Fig. 121). With the cross sections used for the cross beams and the columns, the bending moments which were formed there (Fig. 122) were so large that, if not taken into account by the design, they could unavoidably destroy the frame. With taking properly into account the additional forces and by installing additional reinforcements, the durability of the building could be assured also during the thawing period.

Fig. 120. Sectional view of building of the mining general-purpose combine in Noril'sk
1) antiseismic belt; 2) rock.

To assure the durability of rigid frame-type structures and uncut reinforced concrete beams supported by brick walls erected by the freezing method, it is necessary that the design should take into consideration the effect of sagging of the brickwork on these structures during the thawing. In certain cases the supporting reinforced concrete structure can be worked out in two versions for resting on the walls: a) when erected during the summer, and b) when erected by the method of freezing. In the second case, the sagging of the supports is derived by actual observations.

In designing, special requirements must be satisfied when the work is to be performed under conditions of the winter season. The enclosing mold must be provided with openings and large clearance for cleaning the snow and dirt from the mold and the inserted reinforcing fittings. The low temperature

Fig. 121. Method of calculating the sagging of supports
1) cross section of column; 2) cross section of cross beam.

Fig. 122. Diagram of bending moments caused by sagging of supports of frame's cross beams

of the reinforcing fittings makes the concreting difficult during the laying of the concrete. Steam blown through the mold and the fittings raises the temperature temporarily but brings with it an extremely undesirable ice which covers the fittings and the enclosing mold. The concrete coming in contact with the fittings causes the metal to freeze immediately; with closely spaced fittings, their small clearances become filled with ice and deprives the concrete of further access. To improve the conditions for installing the concrete it is necessary to use clearances as large as possible between the rods of the upper fittings in the enclosing mold (Fig. 123). This can be accomplished by using reinforcing rods of larger diameter, or by installing them in two rows.

Fig. 123. Examples of reinforcing beams of reinforced concrete
A) beams of medium height; B) beams of large height; a) upper zone; b) lower zone; 1) wrong; 2) correct; 3) effective clearances.

The rods in the upper zone when arranged in one row should be moved to towards the edges to form a maximum possible space in the middle part of the beam with a clearance of not less than 8-10 cm. For the fittings located

below and arranged in two rows, it is advisable to increase the number of rods in the first row and to use larger clearances between the rods of the second row, because only a small quantity of concrete needed as a protective layer passes through the rods of the first row. For beams with large height, maximum clearances between the rods can be obtained by arranging even in three rows the reinforcing rods in the upper and lower zones.

Fig. 124. Examples of reinforcing columns of reinforced concrete
a) incorrect; b) correct

In concreting columns, the most difficult operation is to join the concrete with the girders and beams of the roof. The multi-row net of intersecting rods obstructs the passage of the concrete and the abundance of rods interferes with the electrical heating (Fig. 124). The installation pf the concrete and the electrical heating can both be improved by a proper design, For this, it is advisable to increase the cross section of the structures. Each side of the column should be by up to 10 cm wider than in the girder. If a larger cross section is not desirable when it may affect the location of the technological equipment or it may involve an excessive consumption of concrete (for columns of large height), it is then possible to effect only a local thickening (Fig. 125). When electrical heating is used, the grade of the installed concrete will depend on when the structure will be under load. If it is planned to impose the load before the concrete of the structure will acquire the necessary strength, the grade of the installed concrete must be 25-30% higher than specified by the design.

Most difficult at low temperatures is to install the concrete in thin-walled plates and partitions. Snowstorms cover the enclosing mold with snow. The snow is so compressed that considerable manual labor is required for its removal. The compressed snow cannot be removed by blowing compressed air.

Fig. 125. Cross section of column increased where it adjoins the roof; 1) along a-a

The use of steam is not always possible (absence of steam, etc.) and, as was already stated, it results in covering the reinforcements and the enclosing mold with ice.

In plates reinforced or both sides, the removal of snow from the enclosing mold frequently disturbs the position of the rods in the upper row. It requires additional work to correct it. It can be avoided by not using round bends, but to reinforce separately the upper and lower zones of the plate. At this, the reinforcement of the upper zone, when arranged in form of separate nets, will sink into the freshly-laid concrete of the plate.

In concreting thin-walled partitions, the concrete freezes to the reinforcing nets and obstructs the filling of the enclosing mold; this favors the formation of blisters and void spaces. To improve the working conditions and the quality of the work it is advisable, inasmuch as possible, not to use two-sided reinforcement and to use reinforcements cut into sections. In addition, when concreting both supporting and non-supporting vertical partitions, it is necessary to take into account the possibility that the cover located above may become sagged if it rests on brick walls erected by the method of freezing. The thawing and the sagging of the walls will cause the cover to sag; this can either crush the partition located below, or, if the partition is sufficiently strong, it may deform the cover (reverse caving in). To prevent deformations, the design of the supporting partitions must take into account all possible additional loads.

When designing non-supporting partitions, it is recommended to leave at the top a clearance of 5 mm per 1 meter of height of the wall supporting the cover. This clearance is to be plastered after the thawing and sagging of the brickwork.

Assembled reinforced concrete structures

The use of assembled (precast) reinforced concrete is of utmost importance for the conditions of the Extreme North. However, the dispersion and different scale of construction, lack of plants producing precast reinforced concrete in many areas, and transportation and assembly difficulties require the creation of new types of structures. The new structures should be based on the following: sharply lower weight together with high supporting capacity, frost-resistance, and ability to assemble without the use of wet processes (to make a monolith of the assembled parts, additional concreting, etc.), and

also completely outfitted structures. For example, the roof panel must include the insulation and the cover; the cover-panel above the open space under the ground floor must contain the waterproofing, insulation and, if possible, also the floors, etc. The products should be transportable and economical, i.e., they should be made of high-grade concrete with pre-stressed reinforcements made of high-strength steel. It is necessary to create insulated and uninsulated panels made of reinforced cement and long enough to serve as covers and walls of industrial and residential buildings. Precast ferroconcrete has a wide application at the present time in the areas of the Extreme North. Each year brings new improvements for the structures and assemblies.

In Noril'sk, precast ferroconcrete was first used in 1940 for the construction of the carcasses of the mechanical plant. Precast columns were installed into the foundation cups, fastened with wedges, and poured with concrete. In Noril'sk, the conventional methods of performing the work during the winter at temperatures above zero had created many difficulties. The clearance between the foundation cup and the column became packed with snow. The snow could be removed only from the upper parts of the cups. The use of steam in the clearance for heating the bulk prior to its installation resulted in filling the cup with water and ice. In many cases the pouring of concrete into the clearances did not provide the required strength for the assembly. There were cases of columns squeezing through the poured concrete in the cup. This was due either to the freezing of the moist, thawing sand placed at the bottom of the cup, or to the dry sand mixing with the snow and forming a layer which became packed during the thawing. In both cases, a fissure was formed under the butt-end of the column which resulted in shearing the poured concrete by the sagging column.

Fig. 126. Reinforcing the joint of columns with foundation shoes

a) before reinforcing; b) after reinforcing; 1) concrete pad; 2) sand; 3) concrete or asphaltic concrete; 4) precast reinforced concrete shoe; 5) reinforcing ring.

In certain cases the clearance in the cup was filled with asphaltic concrete to enable the joint to gain strength during the winter season. This also failed insofar as the filling of the space in the cups and rigid sealing of the columns is concerned. In other cases it was necessary to use a reinforced concrete monolithic ring to strengthen the joint (Fig. 126). The installation of precast reinforced concrete columns in foundation cups can still be recommended for the areas of the Extreme North, but to prevent the destruction of

the joint the pad at the bottom of the cup must contain thoroughly dried sand which must not become moist before filling the space in the cup. The columns must be reliably secured in the cups with the aid of wedges and the spaces in the cups must be filled with concrete with the temperature above zero, or by using a concrete that will assure the hardening and gain of strength at low temperatures. Electric heating can be emplyod if necessary, but in this case it is recommended before the concrete is installed to warm up the surface of the cups first with hot air or, in extreme cases. with steam and then to apply with special care the electric heating. The grade of concrete for filling the space of the cups must have a strength 30-50% higher tha specified by design.

In Noril'sk columns are joined to foundations by welding, so that the entire load on the foundation is transmitted through the assembled seams. The defect of this method, however, is the large consumption of metal spent for the inserted parts.

Fig. 127. Columns joined to foundations of electrofilter building

For joints subjected to large efforts and especially to bending moments, the use of anchor bolts is recommended, as it was done for the carcass of the electrofilter building. The 17-meter tall precast reinforced concrete columns of of the building have at the botton an expanded shoe which is installed on metal wedges and is tightened by anchor bolts (Fig. 127). The wedges are designed to absorb the loads while construction of the building is going on. The columns are poured with concrete during the summer season.

Many difficulties during the work were caused by joints for the precast beams under the cranes, for the bracings, and for the columns, particularly in places requiring rigid (uncut) connections. The welding of the protrusions

of the reinforcing rods followed by monolithing with concrete was unable, when done in winter, to provide joints of needed quality. A significant part of the joints (and occasionally certain components of the structure) suffered destruction either during the thawing period or during the exploitation of the building. Extremely undesirable is the use of such joints in places subjected to loads before the arrival of the thawing period (joints of columns, cross bars, etc.) because it may result in destroying the structures.

The methods that can be recommended in construction are those used in Noril'sk, namely, welded joints for columns. The tightening bolts and corners are cut off after the joint is welded (Fig. 128).

Fig. 128. Column components joined by electrowelding
1) welded along the contour; 2) sheet gasket; 3) to be plastered with cement mortar along the net after the corners are cut off

Depending on the pattern of the structure, one of the following methods is used for joining beams and cross bars to columns. For rigid joint to the column (Fig. 129), the cross bar is installed on the table of the column and after the aligning is welded to the inserted metal parts. The inserted parts and the assembling seams in the joints are designed for absorbing the thrust of the supports and the bending moment. For an hinged connection to the column (Fig. 130) the cross bar is installed on the table of the column and is secured by welding to the inserted parts only in those places where it adjoins the fins of the corner. The resilence of the reinforcing corner makes it possible to obtain in the joint a hinge necessary to eliminate the possibility of a bending support-moment appearing in the assembled joint. For connecting the wind cross bar of the framework to the columns, the assembled joint must provide not only the hinge-prperties of the supports, but also the ability to shift the beam vertically during the thawing of the brickwork installed during the winter and also to eliminate the possibility of shifting in a direction perpendicular to the axis of the wall. An example of this is the design of joints shown in Fig. 131. The connections used for securing the

cross bar to the columns are made of small corners attached in hinge-manner to the wall of the column. During the assembly period, the corners are suspended to the column, which makes it possible to use them as tables during the assembling. The cross bars are secured to the corners by welding or by bolts. The lugs are cut off after the laying of the walls reached the botton of each cross bar.

Fig. 129. Precast reinforced concrete cross bars rigidly connected to columns
По = along

Fig. 130. Hinge-connection of reinforced concrete cross bars to columns

The defect of such joints is the large consumption of metal, but the possibilty of obtaining joints without using wet processes is such a necessity that the use of joints designed in this manner can be recommended for precast reinforced concrete structures erected under the conditions of the Extreme North. In designing prestressed and precast structures it is necessary to provide the required tension for the reinforcements directly at the plant where they are made, and at construction site, only to assemble the finished components.

The structures operating at low temperatures and under dynamic loads should be made by using reinforcements made of steels that retain the impact viscosity at low temperatures of not less than stated in the specifications GOST 380-57 for Martin-steel 3 or for steels M16 and M18a. The joints must be welded with the aid grade E-42 electrodes. A lower impact viscosity in the reinforcements, inserted parts, and in the seams of the joints may at low temperatures cause the destruction of the structures.

Fig. 131. Connection of reinforced concrete wind cross bars of framework to columns
1) lug 6 to 8 mm in diameter to be cut off after the brickwork is laid under the cross bar; 2) along; 3) clearance.

3. Special features in designs of metal structures

At the present time, most economical for use in the areas of the Extreme North are metal structures. Particularly effective are the metal structures made by the plants located outside the areas of the Extreme North. For example, the metal structures made for Noril'sk by the plants of Krasnoyarsk are 20% cheaper than the structures made in Noril'sk. In addition, the cost of transporting the metal from the producing plants to the construction site consumes about 30% of the Noril'sk cost of the finished structures. Metal structures made outside the areas of the Extreme North save the cost of transporting the excess of metal remaining after production which is later removed as usable junk. Particularly good prospects can be expected from the use of metal structures in the areas of the Extreme North, in view of the use in construction of economical rolled shapes, high-strength steels, and light-weight aluminum alloys combined with new light-weight heat-insulating materials for enclosing structures.

In designing the building for a group of shops in Noril'sk, the use for the roof only of light corrigated, insulated with mineral felt, aluminum alloy panels (weighing 27.1 kilograms per 1 sq. meter of covering) made it possible to obtain the supporting structures of the roof in form of light-weight rod-type of girders , which reduced by 30-35% the consumption of metal for the roof and reduced the cost of the building by 10-15%.

In designing and assembling the metal structures it is necessary, however, to pay attention to the conditions of the Extreme North. The principal factor is the low temperature which brings a reduction in the impact ductility of the metal. According to the data furnished by the handbook Metallovedeniye i Termoobrabotka NTU 1957 (Metal Working and Heat Treatment, Standards and Specifications 1957), the impact ductility of steel-3, etc. is reduced from 10.5 at +20° to 0.8 at -40°.

The brittleness of ordinary metal at low temperatures is so pronounced that even small dynamic loads will cause the formation of cracks and destruction. For example, the motor-car trestle for bringing the ore to the nickel plant had collapsed due to the action of low air temperature; the collapse had resulted from a break over the entire cross section of metal beams, although the load at the moment of the collapse did not exceed 30-40% of the load specified by the design.

Fig. 132. Enlargement of the girder and design of assembly which caused the collapse
a) geometrical pattern of the girder; b) assembly A; 1) seam

The same cause was responsible for several other collapses in Noril'sk. In 1959, for example, during the construction collapsed the the girders of the garage of the central base for motor vehicles, although the actual load did not exceed 40-45% of the calculated load. The girders which were made at the plant in form of separate panels were assembled into trusses in open air. The parts were joined by welding (Fig. 132). The outward deflection of the reinforced concrete columns which supported the girders indicates that the collapse was caused by a break in the lower belt of the truss due to the large forces of the thrust from the upper belt (Fig. 133). With the temperature falling sharply (below -40°) a short while before the collapse, there were heard several sharp loud knocks accompanied with vibration and snow falling off the

the components of the trusses. A study of the causes responsible for the collapse disclosed that a predominant majority of the transverse seams on the the girders which escaped the collapse contained fresh cracks penetrating through over a considerable part of the girders. The formation of cracks, as was already mentioned, was accompanied with loud knocks and vibration of the girder.

Fig. 133. Collapse of metal girders of garage

The formation of cracks in the seams was caused by concentration of the stresses during the three-sided welding. Under ordinary conditions there would have been a redistribution of the stresses due to the plastic deformation of the metal which retained its ductility. The reduced ductility and increased brittleness as a result of temperature falling to minus 40-45 degrees caused the break of the seams. After the destruction of the transverse seams of the cover plates of the lower belt in the corners passing in this section, the stress still remained at a level less than 50-60% of the calculated stress, because the roof had no insulating layer, the cement tie piece with the roof, and no load of the three suspensions to the girder assemblies weighing 16 tons each. The break of the basic corners of the lower belt in which the drop in temperature reduced the impact ductility was caused by the dynamic action of the forces caused by the break of the seam connecting the cover plates in the same section.

The formation of cracks in the seams connecting the components of metal structures built during the summer or in heated shops of the plant have been also observed before the arrival of low temperatures, while in unheated buildings cracks were occasionaly formed several years later after the use of the structures. In several casesthe formation of cracks and destruction of structures were discovered before their assembly as, for example, in the cross bars of the bunkers of the electrosmelting shop of Noril'sk nickel plant. Cracks, both in the seams and over the entire section, were discovered in metal structures which were made at temperatures above zero and inaccordance with the required specifications, but were exposed to frost for a short while without a load.

There were cases of destruction of metal structures caused by the combined effect of sagging foundations and low air temperatures. For several years there was observed a formation of cracks during the winter in the welded seams in certain componenents of the metal structures of the closed coal yard of TETs in Noril'sk, which was designed in 1938-1940 in form of a two-span frame with rigidly sealed supports in the foundations and rigid assemblies at the top. The building was erected by the method of preserving the permfrost

state of the ground beds. The damaged seams were cut off and rewelded again with the load reduced somewhat during the welding.

The winter of 1955 was the beginning of a destruction on a large scale of the main columns of the carcass which created an immediate danger threatening the collapse of the building. The collapse was prevented by installing metal reinforcements and by discontinuing the work of the grab cranes at the emergency section of the building. It was found that the destruction and the deformation were not caused by the vertical load, but by the large bending moment which was formed in the column. This is proven by the nature of the damages affecting the columns (Fig. 134) and also by the fact that the entire system did not collapse after the sheets were torn off the wall of the column and after the bending of the damaged section. The destruction affected primarily the columns of the middle row, but the columns of the outer rows were also damaged to a large extent.

Fig. 134. Damaged metal columns of TETs coal yard in Noril'sk

The main resons for damaging the structures were the deformation of the supports (foundations) of the carcass caused by the thawing of the beds brought about by the underground flow of warm water from the utilities of the TETs and the reduced ductility of the metal due to the low temperature. At this, as shown by geodetic measurements, the upper part of the foundations was deflected considerably from the vertical axis (up to 20 cm) which served as the main cause for the formation of additional bending moments in the columns.

The damaged columns were replaced. The anchor bolts were loosened to reduce the effect on the metal structures by the displacement of the top of the foundations, but the plates of the column's shoes prevented the turning of the supporting assembly and the damaging of the structure continued and became a constant manace of collapse of the building. To prevent the continuing deformations, the upper parts of the columns were equipped with hinges, the lower

belt of the girder was out at the middle support and the anchor bolts of the foundations were loosened. The rigid frame was converted into a statically changeable structure (Fig. 135).

Fig. 135. Carcass of TETs coal yard reduced to statically determinable pattern
a) top view; b) section along 1-1; 1) wind girder; 2) column equipped with hinge; 3) the column is reinforced.

The durability of the carcass is assured by the addition of three abutments connected by horizontal girders which do not hinder the displacement of the top of the abutment in case of possible deformation of their foundations. The horizontal girders are secured by connections to the upper (above the hinge) part of the column. After taking these steps, not a single case of destruction of the carcass was observed during the 5 years thereafter. The study of the performance of metal structures in the areas of the Extreme North makes it possible to offer certain recommendations for their design.

1) Metal structures of building and equipment carcasses, particularly those which are subjected to dynamic loads, must be made of steel able to preserve at low-temperatures an impact ductility of not less than the one specified by GOST 380-57 for St.3, M16, and M18 grades of steel.

2. The design of welded metal structures must strive to reduce the internal stresses which appear in electric welding. Therefore, the design should not specify seams along a closed perimeter, should avoid the joining of components by three-sided seams (longitudinal and transverse), and should avoid the joining of bent and distended components by transverse seams. It is necessary to avoid unneeded seams in the structure, which the calculation makes unnecessary, but, wherever possible, to use intermittent seams. Every seam is the seat of internal stresses which, in certain cases, weakens the structure. The electrodes used for welding must assure the frost-resistance of the seam. For this, it is necessary to use electrodes of the grade which at low temperatures has the same impact ductility as the metal of the structure. These conditions for steel ST.3 are satisfied by the electrodes of grades E-42 and E-427.

3. The cross section of the structures must be selected so that it will be easy to inspect the seams during the erection and during the period when the building is in use. Hidden seams should not be allowed. In sectional cross sections it is necessary to consider the possibility of obtaining seams of good quality and their subsequent repair.

4. Taking into consideration that in the conditions of the Extreme North extensive settling and sagging of foundation beds are possible and that at low temperatures the metal of the structures and particularly the electrically welded seams have a lower ductility, the design must avoid the use of rigid carcasses for the buildings. The construction of carcasses of the pliable type with hinges at the joints; this will make it possible to assure the durability of the buildings affected by large sagging of the ground beds.

5. Taking into consideration that at low temperatures it is very difficult for paint to resist reliably corrosion; also that the kuzbasslak (varnish from Kuznetsk coal deposits) and the oil paints which are usually used do not effectively protect the metal against corrosion (the peel off and fly away together with the corroded metals) and, as a result, the collapse of certain structures had already taken place, it is necessary to solve the problem connected with special corrosion-resiting coatings which will make repeated annual repainting unnecessary. Complete corrosion-resisting coatings must be applied at the manufacturing plant.

CONCLUSION

The aim of the present work is to share the experience in designing and to clarify the certain problems connected with construction under the conditions of the Extreme North. Until 1960, no special scientific work and research were carried out in the city of Noril'sk in the field of design and construction, which explains the absence of analytical, or of detailed economic reasons for the employed or recommended solutions. The considerable progress made in the field of technology, complex mechanization and automation of enterprises, and the introduction of new types of materials for both supporting and enclosing structures make it possible to arrive at new solutions for the planning and designing of buildings and structures, which is of importance for the areas of the Extreme North.

At the present time, the newly established Noril'sk complex laboratory of the Scientific Research Institute (NII) for construction of the Academy of Construction and Architecture USSR, in the work of which are taking part the oldest production workers and designers of Noril'sk, is engaged in complex research; there are reasons to expect that in the near future certain problems mentioned in this book will receive scientifically substantiated solutions and experimentally developed methods for buildings and structures which will satisfy the more severe and special requirements for the Extreme North.

APPENDIX

TEMPORARY INSTRUCTIONS *)

for work with piles by the method of driving and subsequent freezing of piles in the holes

1. These temporary instructions are prepared for work with piles by the method of installing the piles in preliminarily bored holes under conditions existing in merging permafrost grounds of the stable type.

2. Work with piles is permitted when the following are available:

a) data characterizing the permafrost and hydrological conditions of the site used for construction;

b) design of the bed under the piles and a layout of the piles which shows also the location of the underground pipelines.

NOTE: The introduction of changes due to the difference between the actual conditions in the permafrost grounds and those of the design must be first approved by the Design Office.

3. Reinforced concrete piles must be made in plants in accordance with the drawings which are a part of the design for the pile foundations.

4. The production and acceptance of reinforced concrete piles by technical inspectors must comply with the technical instructions contained in part I of the specifications TU 120-55.

5. The layout of the pile axes should be based on a line pertaining to the altitude and vertical reference net. The main axes of the structure should serve as the basic lines. No less than 6 bench marks should be present in each block of the construction site.

6. The layout of the pile foundation is to be accomplished by securing reliably in the location the position of all longitudinal and transverse piles.

7. The layout of the axes of the pile foundation must be formalized by a document to which are added diagrams showing the disposition of the layout symbols and data on the reference to symbols of the State triangulation or other net used as a starting point.

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*) These temporary instructions have been prepared by using as a basis the specifications TU 120-55 for work with piles by the method of installing piles into holes preliminarily bored in permafrost grounds. These instructions have been approved by the chief engineer of the Administration of Major Construction in 1958.

8. The transportation, hoisting, and installation of piles into holes must be performed by taking steps to prevent the overstressing of the material and damaging the piles; this must be in accordance with the plan developed earlier for the organization of the work.

9. Reinforced concrete piles, after their production, must not be transported before they acquire 100% of the strength specified by the design.

10. Before they are sunk into the ground, the piles must be again certified for the compliance with the requirements of TU 120-55.

11. Reinforced concrete piles are to be installed in holes bored earlier by a cable-percussive boring rig.

12. The mud extracted during the boring of the hole is to be collected and kept in a heated container for further use.

13. Before the pile is installed, a clay mixture of fluid viscosity is to be prepared by using the extracted mud and local clay soil; the mixture is to be in accordance with the composition recommended by the permafrost laboratory.

NOTE: The quality of the prepared clay mixture is to be inspected by the construction laboratory.

14. Prior to the installation of the pile, the hole is to be filled to about 1/4 - 1/3 of its depth by the clay mixture heated to plus 30-40 degrees in order to dislodge the mixture to the surface of the grounds when the pile is driven down.

15. The sinking of the pile to the required depth is to be performed, if necessary, with the aid of a vibrating pile-driver.

16. The cap of the pile-driver must be strong and rigidly attached to the pile.

17. The in-plan deviation of piles from the design-position is allowed to reach ±5 cm, and the allowable deviation of the top of the piles from the design-marks is ± 10 cm.

NOTE: For pile deviations larger than in par. 17, the question pertaining to driving additional piles is decided by the Design Office.

18. The work required for leveling the construction site must be fully completed before the beginning of the installation of piles.

19. When using piles of 30 cm. in diameter, the holes must be bored by a bit having 35 cm in diameter.

20. While boring the hole, the boring rig must be located on a horizontal platform clean of snow and ice.

21. No interruptions are permitted between the filling of holes with mud and the sinking of the piles.

22. The work with piles must be performed by keeping a log book for boring and sinking of the piles.

NOTE: Each page of the log book must be numbered and signed by the chief of the section.

23. Loads imposed on pile foundations are permitted after restoring the permafrost state of the grounds around the piles and after the latter become frozen to the bulk of the permafrost grounds, which is established by observing the temperatures.

24. It is recommended to perform the work with piles during the winter season (November-April) when the effective layer is completely frozen; if the work is performed during the summer, the inside of the hole must settle within the entire thickness of the effective layer.

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